Aalto University
School of Science
Degree Programme in Computer Science and Engineering

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Evaluating on-demand public transport against other modes of travel

Case study of Kutsuplus journeys

Master's Thesis
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ABSTRACT OF MASTER'S THESIS

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As cities grow it is essential to reduce private car use, the most polluting and congestion inducing mode of daily transport. While public transport (PT) enables a form of mass transport, PT lacks flexibility due to its scheduled, route-based operations. On-demand PT has been presented as a possible solution to bridge the gap between scheduled PT and private car ownership, but on-demand PT pilots have been scarce and information on the demand of such services is limited.

Kutsuplus was an on-demand PT service that operated based on customer orders in the Helsinki Metropolitan Region (HMR) using premium quality minibuses with automated routing. In this thesis, we quantitatively investigate spatial and temporal characteristics of Kutsuplus, using data for 83,978 realized Kutsuplus journeys. We quantify alternative travel options which could have been used instead of Kutsuplus and investigate whether Kutsuplus was especially used for routes with sub-par PT accessibility.

We find that Kutsuplus featured a PT typical but more lenient temporal demand structure with cross-traffic spatial patterns. We find that the price of a Kutsuplus journey was more expensive than a PT journey, but considerably cheaper than other ordered transport options. After customer pick up, Kutsuplus was a fast choice compared to PT and often comparable to private car use, but customer pick up was often late from the estimate given. We note that the PT options available for replacing Kutsuplus journeys did not seem sub-par when compared to the general PT options in the area.

We recommend that future research still considers whether Kutsuplus use was affected by accessibility of specific PT modes, like rail traffic. Further, if more journey data or user and vehicle specific identifiers are made available, effects of potential congestive collapse and user group specific behavior ought to be investigated.

Keywords:	on-demand transport, public transport, GTFS, mode choice
Language:	English

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DIPLOMITYÖN TIIVISTELMÄ

Tekijä:	Nils Haglund		
Työn nimi: Kysyntäohjattu joukkoliikenne suhteessa muihin matkustusmuotoihin Tapaustutkimus Kutsuplus matkoista			
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Kaupunkialueiden kasvaessa on välttämätöntä tarjota vaihtoehtoja yksityisautoilulle, joka on merkittävä ruuhkautumista ja liikenteen ympäristöhaittoja edistävä kulkumuoto. Julkinen liikenne mahdollistaa joukkokuljetuksen, mutta sen aikataulutettu ja kiinteästi reititetty luonne tekee siitä vähemmän joustavan kulkumuodon. Kysyntäohjattua joukkoliikennettä on esitetty ratkaisuna kaventamaan joukkoliikenteen ja yksityisautoilun kuilua, mutta kysyntäohjattujen palveluiden käytöstä ei ole vielä paljoa tietoa.

Tämä diplomityö tarkastelee kvantitatiivisesti kysyntäohjattua joukkoliikennepalvelua nimeltä Kutsuplus. Kutsuplus liikennöi Helsingin seudulla korkealaatuisilla minibusseilla, jotka toimivat automatisoidulla reititysalgoritmilla. Työn lähdeaineistona toimii 83 978 oikeaa Kutsuplus-matkaa. Työssä verrataan Kutsuplus-matkoja kulkumuotoihin joita olisi voinut käyttää palvelun sijasta. Lisäksi tutkitaan, käytettiinkö Kutsuplus-palvelua nimenomaan reiteille, joiden saavutettavuus oli joukkoliikenteen osalta normaalia huonompi.

Työssä todetaan, että Kutsuplus-käyttö edusti ajallisesti joukkoliikenteelle tyypillistä mutta joustavampaa huippurakennetta, vahvoilla poikittaisliikennepiirteillä. Kutsuplus-matkat olivat kalliimpia kuin vastaavat matkat joukkoliikenteellä, mutta halvempia kuin muilla tilauspohjaisilla kulkumuodoilla. Kutsuplus oli matka-ajaltaan verrattavissa yksityisautoiluun, kun asiakas pääsi kyytiin. Kutsuplus myöhästyi kuitenkin usein asiakkaalle arvioidusta lähtöajasta. Työssä todetaan, että joukkoliikennematkat, joita olisi voinut käyttää korvaamaan Kutsuplus-matkat, eivät olleet muita alueen joukkoliikennevaihtoehtoja kehnompia.

Lopuksi suositellaan, että tuleva tutkimus huomioi, vaikuttivatko joukkoliikennemuotojen, kuten raideliikenteen, saavutettavuuserot Kutsuplussan käyttöön. Lisäksi, jos on mahdollista saada lisää matka-aineistoa tai tunnistaa käyttäjiä tai ajoneuvoja, olisi hyvä tutkia palvelun ruuhkautumista ja pyrkiä tunnistamaan käyttäjäryhmäkohtaisia eroja.

Asiasanat:	kysyntäohjattu liikenne, joukkoliikenne, GTFS, kulkumuodon valinta
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SAMMANDRAG AV DIPLOMARBETET

Utfört av:	Nils Haglund		
Arbetets namn: Efterfrågestyrd kollektivtrafik jämfört med andra sätt att resa Fallstudie om Kutsuplus resor			
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När stadsområden växer blir det allt viktigare att minska andelen av privat bilanvändning, som är bland de mest förorenande och trängselframkallande sätten av daglig transport. Kollektivtrafik möjliggör en form av masstransport, men fasta tidtabeller och rutter gör transportsättet mindre flexibelt. Efterfrågestyrd kollektivtrafik har beskrivits som en lösning som kan brygga klyftan mellan kollektivtrafik och bilister, men det finns inte mycket kunskap om hur efterfrågestyrda service används.

Kutsuplus var en efterfrågestyrd kollektivtrafikservice som trafikerade med minibussar av hög kvalitet och fullt automatiserad dirigering i Helsingfors storstadsregion. I detta diplomarbete undersöks kvantitativt spatiala och temporala egenskaper av Kutsuplus. Som källmaterial används data på 83 978 resor som gjordes med Kutsuplus. I diplomarbetet kvantifieras vilka alternativa sätt att resa kunde ha använts i stället för Kutsuplus och huruvida Kutsuplus användes för rutter med speciellt låg tillgång till kollektivtrafik.

I diplomarbetet noteras att Kutsuplus användes med temporal efterfråga som liknar flexibelt en typisk struktur för kollektivtrafikens efterfrågan, men med spatiala tendenser för tvärtrafik. Kutsuplus resor var dyrare än motsvarande resor med kollektivtrafik, men betydligt billigare än med andra former av beställd transport. Tiden Kutsuplus resor tog kan jämföras med privat bilanvändning när passageraren har stigit på. I praktiken var Kutsuplus ändå ofta försenad från den förväntade tidtabellen. De kollektivtrafikresor som kunde ha använts i stället för Kutsuplus var inte sämre tillgängliga än andra kollektivtrafikresor inom serviceområdet.

För fortsatt forskning rekommenderas att tillgång till olika form av kollektivtrafik, såsom tåg, undersöks för möjliga likheter med Kutsuplus användning. Dessutom, ifall mer data om resor, användare eller fordon erbjudes, vore det bra att undersöka specifika användargrupper och huruvida Kutsuplus som service led av trängsel.

Nyckelord:	efterfrågestyrd trafik, kollektivtrafik, GTFS, val av trafikslag
Språk:	Engelska

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Espoo, 12th of September 2017

Nils Haglund

Abbreviations and Acronyms

BSS	Bicycle Sharing System
CSS	Cascading Style Sheets
CSV	Comma-Separated Values
DH	Daytime Hour
DRT	Demand Responsive Transport
DT	Daytime Traffic
EPH	Evening Peak Hour
ER	Evening Rush
FMTS	Flexible Micro Transport Service
FTS	Flexible Transport Services
GTFS	General Transit Feed Specification
GPS	Global Positioning System
HEHA	Helsinki Region Commuting Area Travel Behavior Survey (henkilöhaastattelu)
HELMET	Demand model for Helsinki region commuting area passenger traffic (henkilöliikennemallit)
HTML	Hypertext Markup Language
HMR	Helsinki Metropolitan Region
HSL	Helsingin Seudun Liikenne (Helsinki Region Transport)
IVT	In-Vehicle Time
KP	Kutsuplus
LoS	Level-of-Service
MaaS	Mobility as a Service
MPH	Morning Peak Hour
MR	Morning Rush
OSM	OpenStreetMap
OVT	Out-of-Vehicle Time
PT	Public Transport
SMS	Short Message Service

Contents

Chapter 1

Introduction

Transportation is important for fulfilling the daily needs of people living in modern urban societies. As cities grow and become congested, it becomes attractive to provide options that reduce the duration, effort, and negative environmental impact of travel. A significant cause of pollution and congestion in city centers is high rate of private car use [10, 100]. Using a private car requires significant portions of space for parking and operating, especially if the vehicle is used only for the transportation needs of one person at a time.

To solve urban congestion, public transport (PT) enables a scheduled form of mass transportation, which is typically subsidized by governments [100]. Some reasons for supporting PT are social through a low price point, environmental through reducing private car usage, and efficiency by reducing congestion in city centers. On the other hand, drawbacks of PT, compared to other modes of transport, may include insufficient coverage, long wait times, long travel times, and the need to transfer between vehicles. Especially private car users may find a scheduled and routed service inflexible.

With digitalization and the increased popularity of smart devices, new possibilities to make transportation more efficient and customizable have been envisioned. Transport users may use location tracking through the Global Positioning System (GPS) and take advantage of web services with advanced routing algorithms to aid navigation and journey planning. Transport providers may provide screens or applications which display real-time information about transport schedules. Services may even automate routing based on the needs of multiple customers to improve service efficiency.

One suggested solution to the challenges of PT is flexible, demand-responsive PT [63]. PT with on-demand features is a compromise between rigid PT and flexible private car usage. Previously, on-demand PT has required call centers and support staff for route planning. Today, digitalization has made larger scale on-demand PT more feasible through automation. On-demand PT has been piloted in various degrees of demand responsiveness. For instance, service-oriented line buses might adapt to the special needs of elderly passengers, or a taxi-like minibus services may compute efficient vehicle routes for serving multiple passengers based on online orders.

An on-demand PT service called Kutsuplus was piloted in central parts of the Helsinki Metropolitan Region (HMR) from October 2012 to December 2015. Kutsuplus could be ordered online or by SMS as a minibus transportation between any two PT stops within the operating area. An important goal of Kutsuplus was to bridge the gap between private car and PT users by providing a high-quality service that adapted its route based on customer demand in a fully automatic manner. The minibus driver followed a route which was computed based on customer orders, and new customers could be picked up before existing customers had reached their destination. Based on a report by the service operator HSL, user satisfaction was noted to have been especially good, but the service was also heavily subsidized during the whole pilot [44]. Demand for increased funding eventually resulted in service shutdown [44].

Previous research on Kutsuplus has mainly focused on management level analysis of the pilot and using qualitative approaches like questionnaires [3, 62, 98]. In user questionnaire responses presented in [98] over a third of Kutsuplus users motivated choosing Kutsuplus by a lack of a good PT connection. While this sounds plausible there is currently no quantitative evidence on what kind of spatial and temporal characteristics Kutsuplus journeys featured and how they compared to competing transportation options in the Kutsuplus service area.

To this end, we study data for 83,978 Kutsuplus journeys, including information on pick up and delivery locations, departure and arrival times, price, the number of passengers, and passenger age. This data set has not been quantitatively analyzed in an open fashion to the best of the author's knowledge. As on-demand PT in today's digital society is still a fresh concept this journey data is a unique opportunity to investigate on-demand PT usage quantitatively.

In this thesis, we focus on the following research objectives:

1. Characterize and quantify Kutsuplus service usage using information on the 83,978 Kutsuplus journeys.

2. Compute journey alternatives for Kutsuplus journeys, using other modes of transport. Compare their differences in terms of travel time and price.

3. Consider PT journey alternatives for Kutsuplus. Investigate PT specific travel impedance features and whether Kutsuplus journeys were made for routes with sub-par PT accessibility.

The first goal of this thesis is to characterize Kutsuplus as a service using the journey data set. We characterize what kind of journeys were made using Kutsuplus and whether there were any distinct patterns or changes in spatiotemporal activity.

After initial characterizations, alternative travel options for each Kutsuplus journey with the corresponding origin-destination pairs and departure times will be computed. Travel modes considered include PT, private car, cycling, walking and on-demand transport (represented by Uber and taxi). The main measures used in the analysis of this thesis include journey duration, distance, and price. For PT, the number of vehicle boardings, and walking distances are also considered. Due to time-dependence of PT operations, travel impedance using PT is measured over a specified departure-time interval rather than at a specific minute.

Based on trends highlighted by Kutsuplus user questionnaire responses [98] we will also attempt to quantify whether the journeys made using Kutsuplus were made for routes which feature sub-par PT availability. The hypothesis is that Kutsuplus was used when PT accessibility was somehow sub-par. Accessibility is considered through travel time, pricing, the amount of walking and transfers required. Reference PT journeys will be generated to quantify possible PT options within the Kutsuplus service area. The reference journeys are compared to the computed PT alternatives which could have been used to replace Kutsuplus journeys.

The structure of this thesis is as follows. In Chapter 2 we review relevant mode-choice literature and existing knowledge on on-demand transportation. We also briefly present the transport system in Helsinki before presenting the Kutsuplus pilot in detail. In Chapter 3 we present the main data sources used in the thesis: the Kutsuplus journey data set, PT schedule data, and the regional travel demand model HELMET. In Chapter 4 we present the methods used for characterizing Kutsuplus journeys, the methods used to compute and analyze alternative travel options for realized Kutsuplus journeys, and how we generate the set of reference PT journeys. We present results in Chapter 5 and discuss them in Chapter 6. In Chapter 7 we make conclusions and suggestions for future research.

Chapter 2

Background

In this chapter, we introduce background information relevant for analyzing the journeys made using Kutsuplus. First, mode choice research dealing with individual-level travel choices will be presented. Second, the travel mode of on-demand transportation will be considered. Third, we introduce the transport system in Helsinki during the Kutsuplus pilot. We conclude this chapter by introducing the Kutsuplus project in detail.

2.1 Mode choice

Mode choice refers to the transportation selection problem that people face when they wish to get from one location to another. In an urban environment, there are often multiple different travel modes available and mode choice is affected by various factors. In addition to mode-specific price and travel time, also features like vehicle transfers, effort, journey purpose, and more specific Level-of-Service (LoS) considerations like available seating, convenience, predictability, cleanliness, and safety affect mode choice. [53, 60, 86].

A common framework for **mode choice modeling** is generalized cost, which attempts to quantify the amount of disutility of travel by giving value to different journey factors [53]. For instance, travel time inside a hot bus would likely be quantified as having higher cost on a summer day than time inside a cool bus, even if both travel options would take the same amount of time to reach the destination. The cool bus would likely feature a lower generalized cost through higher travel comfort. There are also various refined mathematical choice models available. For example, logit models have been commonly used to model discrete mode choice [16, 57], while other research has focused on inferring latent variables from qualitative and behavioral patterns of travelers [64, 89].

For the purposes of this thesis we focus on understanding key features that affect mode choice in an urban environment. Different modes of travel inherently feature subjective perspectives on the effort and cost involved, based on for example fitness and income level, which we will not focus on differentiating. Thus, the background research presented here should be considered a reference for generalized urban commuters and not precise facts. Also, as most results presented are based on questionnaire results about choice, it is good to remember that possible effects of justification bias may be present.

Even though monetary **price** may appear a relatively transparent factor in mode choice scenarios, the available transportation options, and the way they are utilized, strongly affected individual level considerations [53]. For example, frequent car users would probably not find initial investment or maintenance costs as significant as someone who owns a car but uses it very seldom. Fuel may be cheaper than using a taxi, but the costs of purchasing a car, acquiring a driver's permit, and parking may be substantially higher.

When considering **travel time** in mode choice contexts, it is common to deal with In-Vehicle Time (IVT) and Out-of-Vehicle Time (OVT) separately to enable more precise time-value quantifications [96, 97]. It is beneficial to valuate differences in IVT and OVT travel time through multipliers or time penalties, instead of monetary values, because time units provide a more transferable global measure [53]. Travel time values are usually significantly higher when IVT or OVT is uncomfortable, unsafe, or stressful [60, 99]. The distinction of OVT and IVT is mainly used for PT contexts, which may feature waiting or vehicle transfers. OVT for other modes could be quantified through walking to and from transport; unfortunately, such data is not readily available. Thus, often mainly journey duration as a single value has been considered, even though it is commonly agreed that multiple features may significantly affect mode choice [53, 58, 86, 97].

IVT has largely dominated travel time research, possibly because it is a relatively straightforward connection to money through operational time, and quantifying customer and driver time in vehicles [53]. While the valuation of IVT may vary significantly between users of different travel modes, it may also vary between users of different PT modes [96, 97]. But even though PT options may be fine-grained to vehicle type choice, these considerations will be ignored in the scope of this thesis.

The two main types of **OVT** are **waiting** for transportation or **walking** legs from origin to transport access or from transport egress to destination. The valuation of OVT in walking or waiting may be significantly affected by the effects of weather, time, and area [60]. If walking is a fast travel option it might well be preferred on a sunny day, while calling a cab or spending some time waiting for PT option might be preferred if it is raining. For a generalized PT context OVT is usually valued a few times higher than IVT [60]. PT may specifically also feature multiple OVT periods during a journey, as transfers between vehicles may significantly affect PT usage [38].

Transfers are a major point of interest when considering travel modes related to PT. A transfer means that a traveler changes between PT vehicles. Transfers generally cause additional unwanted effort, because they either entail OVT waiting or the risk of having to wait for almost a full headway, if the transfer connection is missed. Thus, in mode choice considerations, a time-penalty is often added to the IVT measured journey duration for each transfer on a journey [38]. This means that even if a journey with transfers is preferable due to a shorter overall travel time, with a transfer penalty this may no longer be the case. A common value for a transfer is 10–15 minutes of IVT [60], especially when good passenger information and comfortable waiting conditions are available [53]. It is worth noting that transfers also force people to make cognitive effort and interrupt possible activities that may make traveling more enjoyable. [7]

The required cognitive **effort** may decrease when one is simply a passenger in any form of transport and not a driver. While using a private car may provide more freedom, efficiency, and control, it may not always be preferable due to constant concentration required when operating a motorized vehicle. Observations supporting this line of thought have been made in research [99], where stress levels of car and train commuters in New Jersey have been compared. It was found that train users experienced less stress and fewer negative moods than car drivers making similar trips, possibly due to the reduced effort and greater predictability of train travel [99]. The stress levels of train commuters also significantly declined after service improvements reduced the need to transfer [99].

The effects of **journey purpose** have been highlighted by research in which British rail users were interviewed [61]. Most of the interviewed found that their travel time had positive utility at least sometimes and was not simply wasted, while less than every fifth reported time spent on a train as wasted time. Significance could be found in for example working, studying, reading or socializing with other passengers or using a mobile device. The portion of travel time devoted to productive activity was higher for business than commuting or leisure travel and increased with journey duration [61]. Travel time research by the Finnish Transport Agency has also reported that the valuations of time for leisure, work, and recreation are quite different and not described simply by features like income level [86]. The PT authority of the HMR, HSL, has also found that journey purpose appears to affect the perceived time penalty for transfers, quantifying transfers as cheaper for regular and business journeys than for elderly passengers and leisure travelers

[38].

While ordered modes such as a taxi may feature a high price compared to PT, they provide personal service and a direct connection between origin and destination, resulting in a higher **Level-of-Service** (LoS). But as PT is usually meant to provide a basic level of service, to enable mobility for all people, it usually does not have many LoS options available [60]. So even though travelers appear more sensitive to changes in travel time than price [6], it is often not possible to pay extra for faster transport or a less crowded vehicle in PT. While a higher LoS benefits all transport users, LoS based classes or improvements could tempt new users to consider a mode, when they find service quality to be on a sufficient level [60].

LoS targeting for PT is quite difficult, because users have very subjective and different valuations for travel time. This holds true even for short trips in urban areas, which would feature a large potential for replacing private cars with other modes of travel [65]. Some possibilities for LoS targeting of PT have been suggested through a framework [52], by which the aversiveness to transfers could be reduced. Key considerations include providing cheaper fares for journeys with transfers, optimizing operational aspects like headway and schedule reliability, and taking to account physical and aesthetic aspects of the wait and transfer environment [52].

Still, transfer considerations may not provide enough mode change incentive for car owners. As a potential solution, a concept called Mobility-as-a-Service (MaaS) has been introduced. MaaS is a service type that distances users from owning personal vehicles in favor of transportation solutions that may be consumed as a service [14]. Some MaaS solutions may provide access to multiple modes of transport, while others may focus on sustainable transportation through journey pooling or vehicle rental. Ideally, these MaaS solutions could provide access to a cost-efficient but high quality LoS without the need to own a vehicle, thus making sustainable mode choices possible even for private car owners.

2.2 On-demand transport

In this thesis, we regard on-demand transport as a form of personnel transportation which features some degree of demand based flexibility. This flexibility may be visible in location, fare, or time. In PT contexts, on-demand transportation is often referred to as Demand Responsive Transport (DRT) or Flexible Transport Services (FTS). Various more specific terms have been coined to characterize specific kinds of on-demand transportation. For example, the Kutsuplus service has been called an on-demand minibus service and a Flexible Micro Transport Service (FMTS) to convey its nature more fully [62, 98].

On-demand transportation may in general either be fully demand based or simply demand-flexible. Fully demand based services do not move while there is no demand, while demand-flexible transportation may follow schedules or routes, adjusting operation based on demand. Some services may require orders be placed even a day in advance, while others only require short notice.

On-demand PT is situated between personal ordered transportation (taxis) and static public transportation. The responsivity and LoS of an on-demand transport service may vary greatly. The field has been quite active during the last decade, with multiple short-lived pilots for the public appearing in cities such as Helsinki and Krakow. Unfortunately, most of these have faded to silence. Still, more long-lived projects do exist as paratransit, for example the MetroAccess Paratransit in Washington DC has been active for many years, but using the service is limited to special groups and strongly subsidized through the local PT authority [82].

We differentiate between rural on-demand transport and urban on-demand transport, because the focus of this thesis is to inspect on-demand PT through Kutsuplus, which was an exclusively urban service. Generally rural on-demand PT is aimed at areas where demand is usually low and thus the costs of a frequently scheduled regular bus line would not be justifiable [95]. On the other hand, urban on-demand transportation may complement the rigid LoS options of PT by offering faster or more comfortable transportation [54].

Locational flexibility can vary from full door-to-door mobility, like taxis, to specific access and egress locations, like conventional PT. While limitations may appear less attractive to customers used to a private car, they may prove to be more efficient when operations are exclusively focused on high-demand areas [90]. In practice, as most urban on-demand PT lines are targeted at special groups like elderly, disabled, or children [54], they often offer some degree of flexibility for egress locations, even if vehicles generally follow a specific route.

Fare flexibility may be implemented in a pre-informed manner, where for example certain hours and days feature a higher base price due to demand. Another option is to increase prices when demand exceeds transportation capacity. The latter option has been used by Uber as so-called surge pricing [13]. While a high return makes working more lucrative, it may potentially lead to very expensive rides, as was noted by Uber customers on New Year's Eve, who reported up to 10x pricing [59]. Kutsuplus as an on-demand PT solution opted for a static pre-informed pricing model, where customers could expect a shorter journey duration for a higher price, thus enabling a flexible

LoS in both fare and travel time [44].

Time based flexibility for journey duration is not a common approach for on-demand transportation. Possibly because users are more sensitive to changes in travel time than price [6], thus the lack of clear temporal estimates might be unattractive for non-leisure transport.

While previous on-demand PT services have focused mainly on special groups as a complement to conventional PT, recent developments [63] are now considering services which target the general public. The potential of on-demand PT has also been recognized in the context of modal shift policy goals [62], in practice alleviating the shift from using a private car to PT. Focus group interviews about aiding the shift to on-demand transportation from car, were also performed in research leading up to the Kutsuplus pilot [91], potentially influencing service design decisions.

A problem many on-demand transport services seem to face appears to be related to service scaling. While on-demand PT could be a viable complementary mode for urban transport, if fleet size can be increased to a significant level [55], the author is not aware of on-demand PT for the general public where the fleet size would have been substantial. If there is insufficient customer demand and vehicular capacity, the on-demand PT service might simply become a subsidized taxi service, where journeys are faster, but pollution and maintenance costs are relatively high. Still, short-term compromises in service profits could be considered investments by public actors, to provoke a modal shift away from private cars.

The Mobility-as-a-Service (MaaS) approach is present in contemporary on-demand transport considerations, which attempt to account for new modes of transport. For example, in various American cities on-demand transport like Uber can be thought to either complement or substitute for PT, depending on the prevailing PT service level [13]. Carpooling has been viewed as first-aid for people using private cars only for themselves. In a rural environment forms of journey pooling have been piloted by services like Uber Commute, where commuters may share their ride and costs with neighbors. In more urban contexts services like Split and Lyft Line have gained attention as ride-sharing options.

2.3 Transport system in Helsinki

To understand the operational environment of the Kutsuplus service, we review the transport system of the HMR during the Kutsuplus pilot (2012–2015). We focus mainly on the Kutsuplus service area, which featured only parts of Helsinki and Espoo municipalities. We introduce background information for the Helsinki capital region, because it is the smallest commonly used classification including Helsinki and Espoo. The Helsinki capital region consists of Helsinki, Espoo, Kauniainen, and Vantaa. [27] We consider spatial demand for transportation in the region together with available data in Section 3.3.

2.3.1 Overview

During a typical weekday in 2012, the 1.1 million residents of the Helsinki capital region made over 3 million journeys inside the region, averaging to around 3.4 journeys per person. Of the journeys, 27% were made by walking, 7% by bike, 27% by PT and 37% by private car [27]. 58% of adults were classified as primary car users, while 42% were classified as PT users. To better describe weekday transportation usage only journeys lasting under 100 minutes were included in the research and thus it was computed that capital region residents used on average 73 minutes a day for transportation. [27]

2.3.2 Public transport

Helsinki Region Transport (HSL) is the PT authority of the HMR. HSL is subsidized by the member municipalities of the region, including Helsinki, Espoo, Vantaa, Kauniainen, Kerava, Kirkkonummi, and Sipoo. Single ticket prices for adults are approximately 3–5 euros, with significant discounts offered for special groups and smart card usage.

For the whole HSL region in 2015, 356.8 million journeys were made using HSL PT. 1.9 million journeys were made using ferry, 55.2 million using tram, 56.5 million using train, 62.9 million using metro, and 182 million using bus. [42]

In 2015, the HMR PT network featured 302 PT routes in total. 272 bus routes, 2 metro routes, 12 tram routes, 14 train routes and 2 ferry routes. [42] The general organization of the HMR PT routes have been visualized in Figure 2.1.

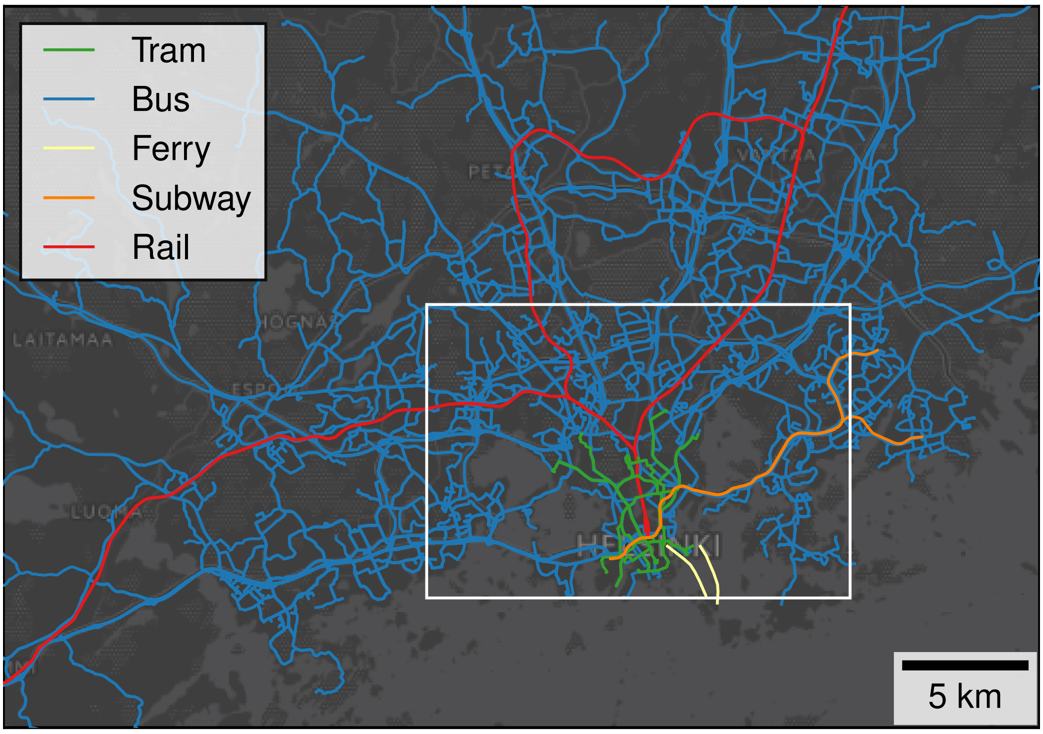


Figure 2.1: HSL PT routes from 9/2015 visualized using code originally by [58], utilizing Smopy (`https://github.com/rossant/smopy`). The white box roughly limits the full Kutsuplus service area, for more details see Section 2.4.3. Background map: © OpenStreetMap contributors, © CartoDB.

HSL has released passenger information that shows annual numbers and portions of trips between 1987 and 2012 and month-level variation [32]. The main trend is that PT is used less during the summer vacation month of July, with some reduced demand also reflected to June and August. Approximately 16 million journeys were made monthly in Helsinki, 5 million as regional transport and 1 million in both Vantaa and Espoo municipalities each. [32]

According to HSL's customer satisfaction surveys PT is perceived as a reliable mode of transport, with over 85% satisfaction scores during the years 2012–2017 [37]. Service punctuality has generally been appreciated, especially for the metro and bus lines, but not so much for the local train lines [37].

As a significant change in PT during 2012–2015, the Helsinki ring rail line was opened in summer 2015. The ring rail line provides a direct train connection to the Helsinki-Vantaa airport. HSL reported a significant increase in train users' satisfaction and a decrease in taxi usage around the airport. [43]

On-demand PT

Besides Kutsuplus (2012–2015), there have not been on-demand PT services in the capital region aimed for the general public. The closest was an order-based service "Vantaan kutsuohjatut lähibussit" from August 2015 to December 2016 in Vantaa municipality. The service functioned as three fully order-based minibus lines with normal HSL pricing. The service was designed with elderly and customers with disabilities in mind. The service operated between 9 AM and 3 PM and could be ordered by calling a phone number at least one hour in advance. The service was shut down due to very low demand, where some lines were not even used daily. The low demand was attributed to difficulties placing orders and finding service access points [45].

There are still some fixed-route urban neighborhood lines (Jouko, Lähilinja, Lähibussi) available, which are designed to serve mainly elderly and mobility impaired people in the capital region. The buses are low-responsive as they follow predefined routes, but drivers support customers with special needs, thus buses are often quite flexible about access and egress locations [19].

In a rural environment, the bus lines 918 and 919 are the main demand based PT lines that operate inside the HMR. These lines serve the scarcely populated Kirkkonummi areas with otherwise low demand and accessibility to PT, also considering the needs of special groups. Transportation may be ordered for typical office hours by phone, from one hour to up to two weeks in advance. [33].

2.3.3 Ordered transport

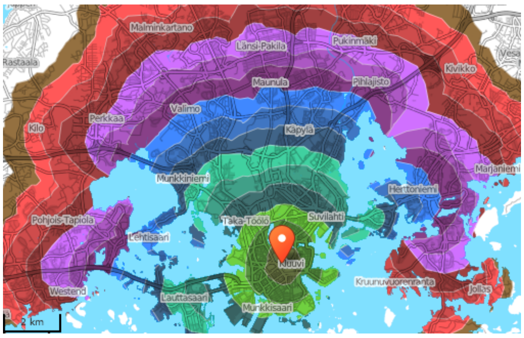
The main personal forms of ordered transport in the HMR have been taxi and Uber. Taxi and Uber orders may be placed by phone or using mobile applications. Both services provide personal door-to-door transportation at a higher price point than PT.

Taxi pricing in Finland was regulated by the government during the Kutsuplus pilot, and it was generally acknowledged that the maximum price is in fact also in practice the minimum price for short taxi trips within the HMR. [77] The amount of taxi permits granted and the pricing of taxi services will likely be deregulated in 2018 [78].

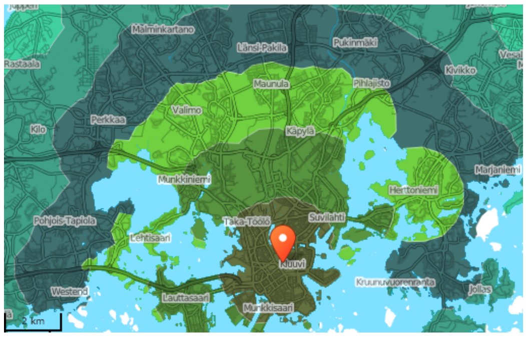
Uber has operated as a competitor for taxi with two service classes in the HMR, Uber POP, and Uber BLACK. Uber POP is based on drivers using their personal vehicles and provides a low entry price point and requirements for potential part timers. BLACK is for professional drivers. POP has spread controversy through the fact that taxi services are regulated, leading up to police investigations about illegal taxi services. Thus, Uber POP announced it is now on a one-year break, starting August 2017.

2.3.4 Cycling and walking

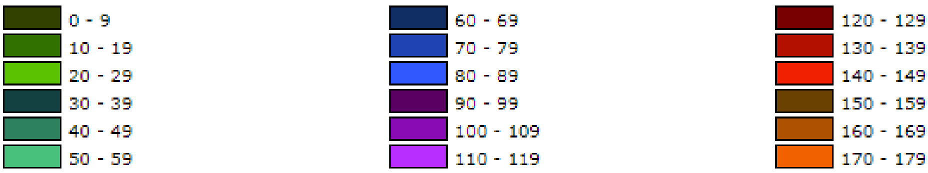
Cycling and walking are central and viable modes of travel in the HMR. For a grasp of travel times from the downtown Helsinki center to the edges of the Kutsuplus service area in the HMR, see Figures 2.2a – 2.2c.



(a) Travel time estimates for walking (5km/h)



(b) Travel time estimates for biking (16km/h)



(c) Travel time estimates for 2.2a and 2.2b in minutes

Figure 2.2: Screenshot of http://mak.hsl.fi/ (30th June 2017). Rights belong to HSL and BusFaster, map data by OpenStreetMap.

There are reportedly around 3000 km of cycle paths and 12000 park&ride spaces for biking in the HMR, with strong commitments by capital region municipalities to increase the modal share of cycling from around 7% to 15% by 2020–2024 [22]. Around 40% of Helsinki residents interviewed and 66 % of Espoo residents said they are content with the cycling options available, though especially Helsinki residents were quite unsatisfied with winter maintenance as only 28% were satisfied or relatively satisfied [22].

Cycling as a mode and even as a feeder transport form, where people may change mode to PT, has been considered and accounted for by traffic authorities in Helsinki [68, 69], so it still seems safe to expect suitable terrain and parking solutions to be available most of the time for commuting. For a good interactive overview of cycling routes, see for example `http://ulkoilukartta.fi` (Referred 7/2017). Different bicycle sharing systems (BSS) have also been piloted in the HMR [83], but no BSS was available during the Kutsuplus pilot.

Even noting the high satisfaction of bikers, the parts of HMR where Kutsuplus operated are quite urban. The city center has a high density of traffic lights, as shown in Figure 2.3. While there are solutions for avoiding congestion and waiting, using specialized routes for walking and cycling, mobility in large parts of the central HMR is significantly limited by traffic lights.

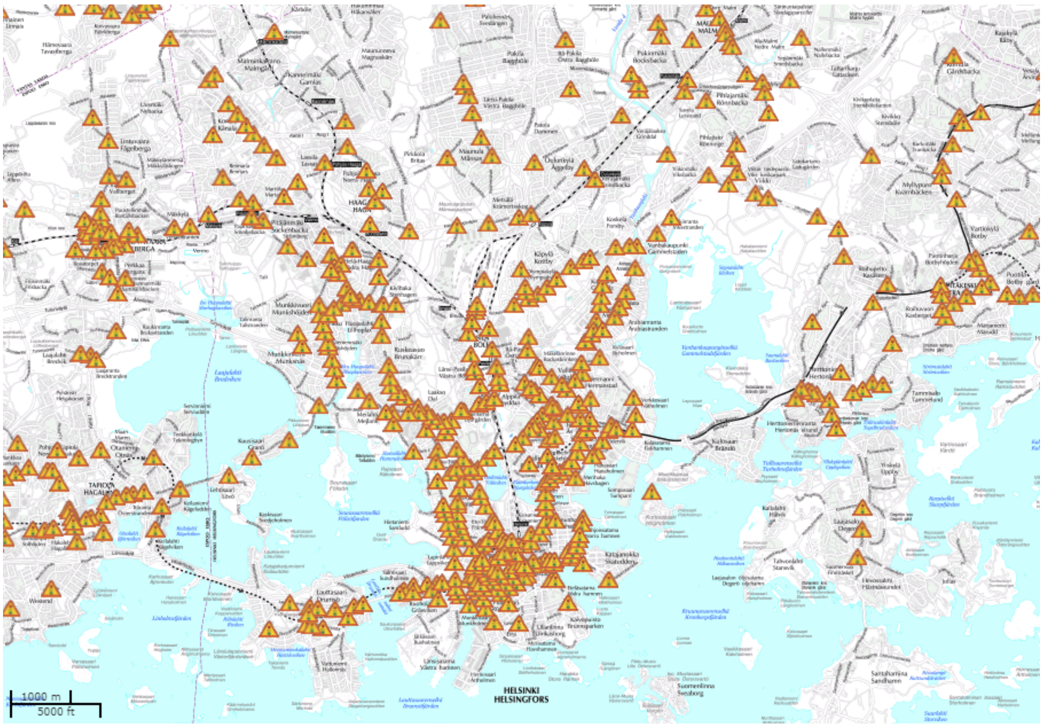


Figure 2.3: Traffic lights in the HMR covering the Kutsuplus service area. Screenshot from the HSL journey planner, rights belong to HSL, CGI, and Karttakeskus `https://pk.reittiopas.fi/`.

2.3.5 Spatial accessibility overview

General spatial accessibility for the HMR, measuring how good transportation options are available, has been quantified by HSL in accessibility studies from 2012 [31]. SAVU is a model that considers accessibility for PT, cycling/walking and private car. In the model, HSL divides the HMR to seven SAVU accessibility zone categories (see Figure 2.4). 20% of the HMR population live in each of the smaller SAVU zones I–IV, 10% in SAVU V and 5% in both SAVU VI and VII. In 2012 the population for each of zones I–IV was around 268,000 people.

The SAVU categories attempt to quantify what sustainable transportation options are available to meet the transportation demand of the region. Thus, while the regions may be compared to each other it is not directly quantifiable how much more accessible these categories are. [31] SAVU zone I in the Helsinki city center has access to good sustainable mobility options to meet demand, through very frequent PT connections or walking. On the other hand, SAVU zones VI-VII in the periphery do not in practice feature viable, PT but require private car use for most journeys.

Travel mode portions for the SAVU zones relevant to the Kutsuplus service area (see Section 2.4.3) are listed in Table 2.1. When PT accessibility goes down, the portion of car trips goes up. It is worth noting that walking in the city center is a common form of transport. And per HSL models, PT accessibility in the Kutsuplus service area ought to be fair.

Table 2.1: Metrics for journeys started in corresponding HSL SAVU zone in 2012 ([31])

Mode portion	SAVU I	SAVU II	SAVU III	SAVU IV
Walk or bike (%)	43.9	31.6	28.4	25.3
Car (%)	23.7	35.6	42.5	51.6
PT (%)	32.5	32.8	29.1	23.1
Average trip length PT (km)	7.4	9.5	11.2	13.9
Average trip length Car (km)	6.5	8.5	9.2	10.3

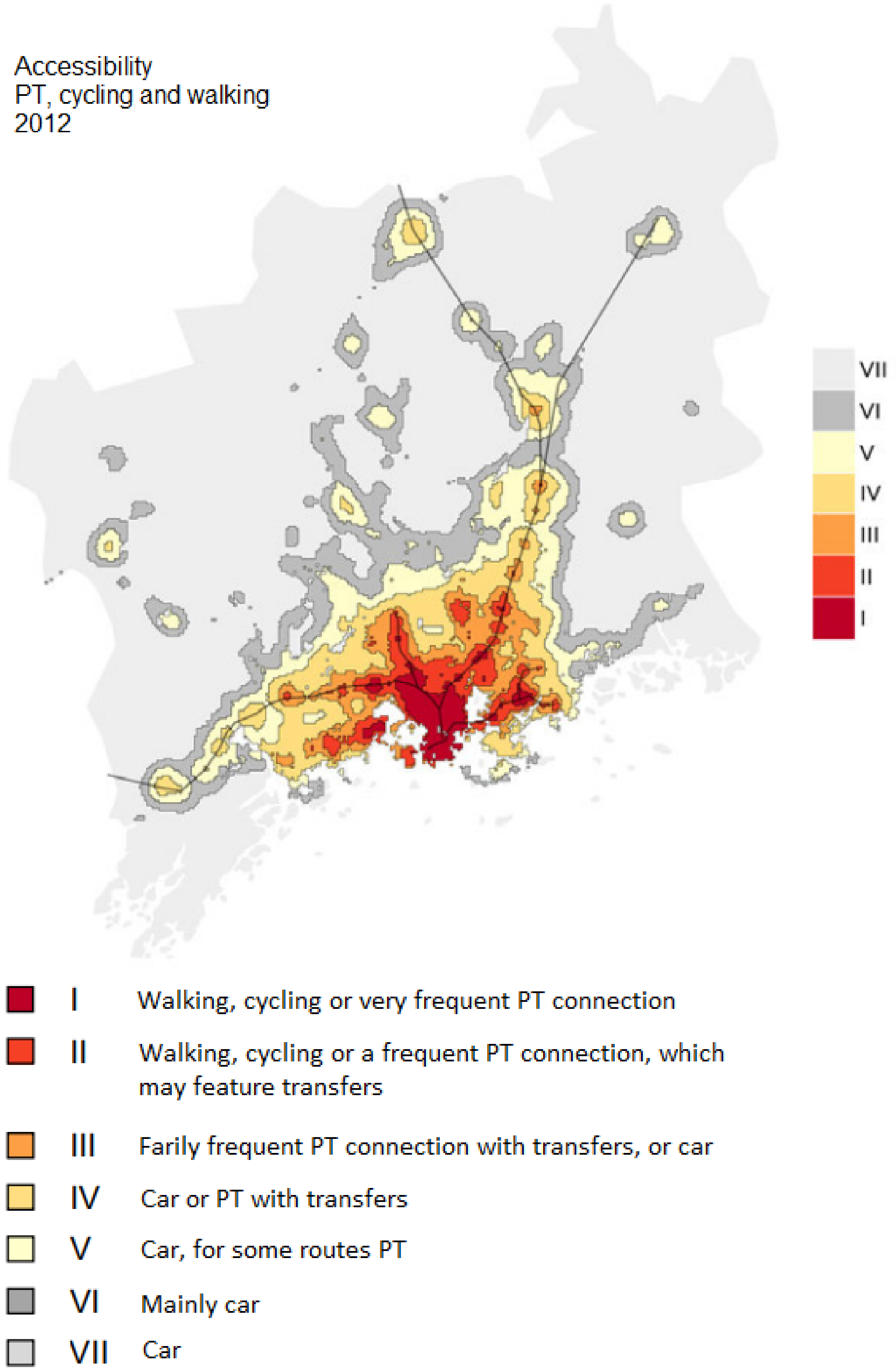


Figure 2.4: SAVU accessibility zones (Translated from [31]). For each zone is depicted what transportation options are available to meet the transport demand of the region.

2.4 Kutsuplus pilot

Kutsuplus [44] was an on-demand PT pilot from 2012 to 2015. The service was operated by HSL and Split Finland OY, subsidized heavily by municipalities of the HMR, and aimed for the general urban public. The service operated with minibuses in parts of the HMR and was designed to be a high-quality PT travel mode to compete with private cars. The key feature of the service was that the routing and journey pooling was fully automated. Kutsuplus bus drivers were given instructions on where and how to proceed based on customer orders. The bus could pick up new customers mid-route and adjust its route accordingly, to enable higher efficiency. In general, the service gained very favorable user satisfaction scores, 4.7/5.0 [44] when compared to around 4.2/5.0 for other HSL PT during the Kutsuplus operating period [37].

The term Flexible Micro Transport Service (FMTS) has been used previously to characterize Kutsuplus [62, 98]. The term suits it well as the very high-quality minibuses could seat up to 9 passengers at a time, thus offering a highly personalized service on a relatively small service area. The pilot started with around 0.3 trips per vehicle hour and ended with approximately 1.8 trips per vehicle hour. On popular days the frequency increased to multiple trips per vehicle hour, despite this the service was still heavily subsidized [44, 62].

Per the public transport legislation of Finland [72] Kutsuplus was possibly not officially an on-demand PT service, because funding was not market based, nor did the service always combine at least three customer orders to one route, as is specified in the legislation. While this may not have affected the service operations, it shows that new forms of PT mobility and MaaS are new concepts from a legislative perspective.

2.4.1 Project timeline

A timeline providing an overview of the most significant phases of the Kutsuplus service is shown in Figure 2.5. Please note that the events present in the timeline are discussed in later sections, but the timeline may provide a useful overview and reference for readers.

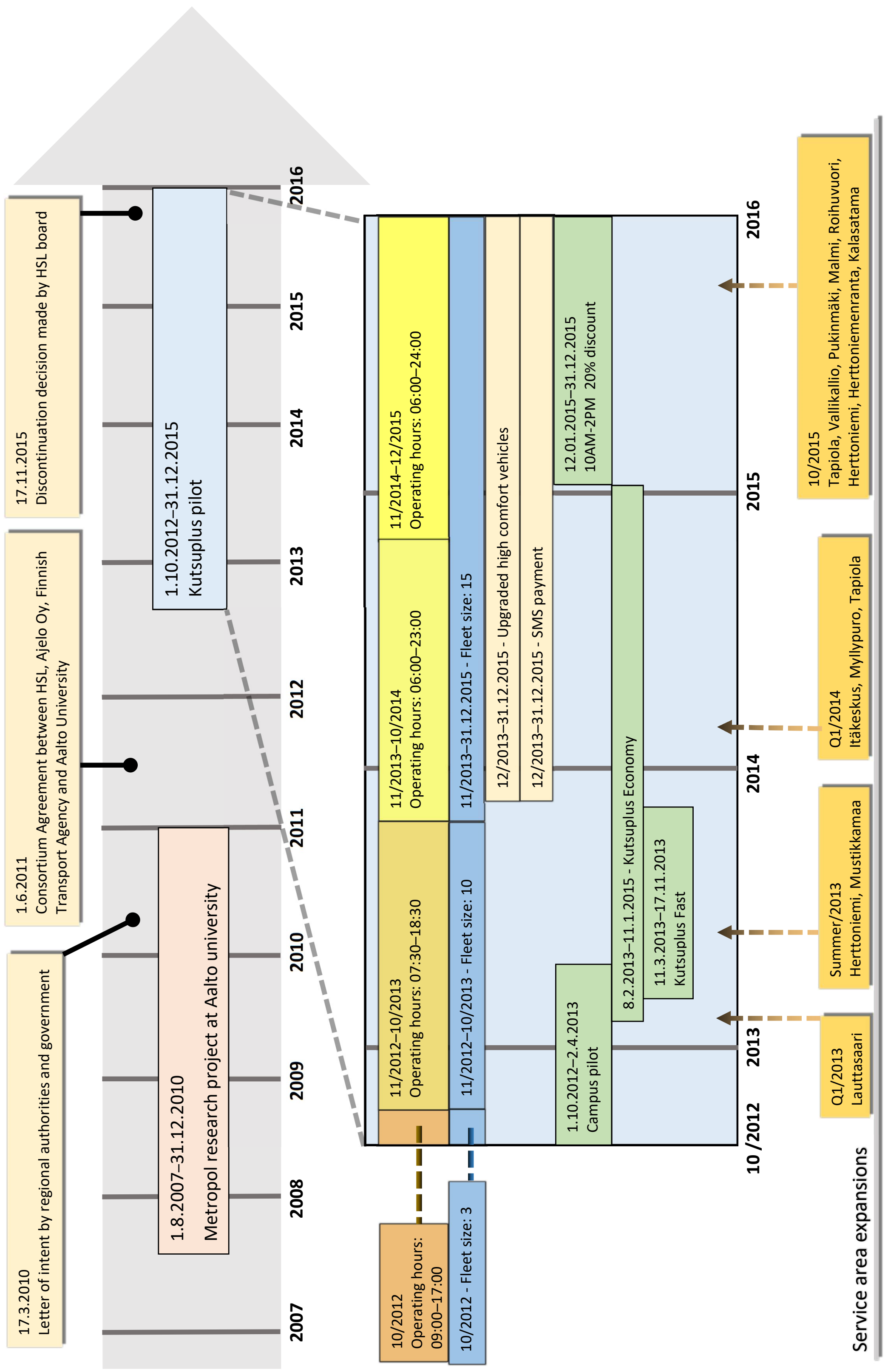


Figure 2.5: Kutsuplus service timeline

Research leading up to Kutsuplus started in 2007 at Aalto University as the Metropol project (2007-2010) [5]. Metropol considered DRT in metropolitan areas and effectively researched the possibility to complement the existing PT network with a new high quality and cost-efficient PT mode that could compete with private car usage. The Finnish Funding Agency for Technology and Innovation TEKES, Helsinki City Innovation Fund, Helsinki City Transport (HKL) and the Ministry of Transport and Communications supported the project.

Some aspects considered in Metropol were simulating the routing for multiple vehicles [46] and adaptively inserting journeys to the route of a single on-line vehicle [49]. Also, congestive collapse and its prevention was considered [47]. Congestive collapse occurs when a journey gets assigned to an unsuitable (e.g. overly loaded or remote) DRT vehicle. To avoid congestive collapse vehicles could be pro-actively added to high-demand areas or reject orders if at full capacity. Dynamic pricing, based on system load, was also considered an option [47].

While a common assumption is that DRT is especially useful for combating remote and scarce demand where line buses would be expensive to operate, Metropol research on journey pooling [90] reported that where spatial demand is high a DRT may thrive because journey pooling and trip combining potential increase significantly.

The specifics of the Kutsuplus routing algorithm are not public, but taking to account the amount of co-operation of the various actors involved with Kutsuplus and citations of Metropol papers, most likely significant amounts of work rely upon Metropol research. For reference a dissertation on DRT routing [50] and stochastic modeling of vehicles in an on-demand transport system [48] may be interesting.

Results from the Metropol project implied that if the transportation fleet size is increased to sufficient levels, it is possible to create an on-demand transport service that is based on smart routing for pooling journeys, with a clear market gap for trip pooling in the urban HMR [40]. Thus, a letter of intent was signed on the 17th of March 2010 by the capital region cities and Finnish governmental offices to improve the competitiveness of the greater HMR. An important goal was to improve PT connections between HMR universities and colleges, which would be achieved by launching an on-demand transport pilot with the help of the Finnish government.

On the 1st of June 2011, a consortium agreement was signed between HSL, Ajelo Oy (Split Finland OY), the Finnish Transport Agency and Aalto University for an initial Kutsuplus pilot [62]. The initial aim of the pilot was to use a small fleet of vehicles to test a fully automated on-demand PT service as a travel mode in the HMR. [40] Short term goals of Kutsuplus were to provide a travel mode option that could compete with private car use and reduce congestion, parking problems and negative environmental effects [44]. Long term goals of Kutsuplus were to provide a service that would complement PT in the HMR and achieve significant mode shift from car to PT [62].

From a user perspective, Kutsuplus could potentially replace cumbersome transfers or long headways for some PT connections. At the very least the aim was to provide a higher IVT quality compared to conventional PT. Privacy was also considered in Kutsuplus design. Users had the option to remove history information about specific trips made using Kutsuplus through an Ajelo web portal [15].

Kutsuplus started as a closed campus pilot in October 2012, opening to the general public in April 2013 [3]. After the service started public operation it quickly became apparent that service growth goals were not met. HSL established expansion targets, where the number of Kutsuplus vehicles would be 45 by May 2014, with 100 vehicles driving on weekdays and 60 vehicles on Saturdays by year 2018. In practice, the service managed to scale to 15 vehicles. Though, despite the limited vehicular capacity, the efficiency of the service rose to a level between the efficiency of a typical traditional bus service and that of a typical taxi service, when considering trips per hour. [44]

Though user amount were steadily on the rise the official discontinuation decision for Kutsuplus was made by the HSL board on the 17th of November 2015, because HSL as the PT authority was not seen as the right entity to be the transport service provider by the municipalities funding Kutsuplus [40, 62]. It was thought that this on-demand priority service was not in-line with HSL's core mission and competence as an PT authority. In addition, environmental impacts were heavily disputed, especially as the core service area of Kutsuplus only covered the central HMR area with arguably the highest quality and most effective public transport services [62].

HSL informed that using Ajelo/Split IP created for Kutsuplus in other kind of projects would, according to Ajelo/Split, take at least one year of migratory work [40]. HSL also made clear that there are no plans to support a market-based form of on-demand public transport, even though it was also recognized as one of the only viable plans for the technology in the future. Other actors in the transport field, which were not named, were apparently very interested to start operating Kutsuplus after HSL, but felt the unsubsidized market-based model included challenges they were not equipped for, especially as the Ajelo/Split IP was not readily available [40]. Automation, through autonomic vehicles, was considered an important trigger for financial viability in the future [62], because as shown in [55], professional drivers usually make for the largest portion of daily service operating costs.

2.4.2 Using the service

Kutsuplus journeys could be made between any PT stops within the service area. While the service was not designed for special groups, to improve service accessibility, hundreds of access and egress stops exclusive to Kutsuplus were also added to the Kutsuplus service area. These were referred to as virtual bus stops. [44]

Orders could be placed 15 minutes before operating started in the morning. In general, it was possible to request pick up as soon as possible, but how much in advance orders could be placed varied from 30 minutes to up to two hours in advance. Unfortunately, the time at which these variations were in place is not clear. This goes to show that customers had to adapt to the service flexibility they were currently provided. HSL stated that 35% of pick ups were realized within a +/-30 second range of the given pick up time, which seems precise for a flexible service [44].

Orders were primarily made through a website, where users could either input stop IDs or select the stops they wished to use as journey origin and destination from a map. Upon selecting stops, the user was suggested journey alternatives if transportation could be arranged. When ordering, it could always happen that vehicles were not available, but statistics on failed order attempts have not been published. [44]

Kutsuplus did not feature a mobile application like many modern-day counterparts, rather the website also featured a lightweight option designed for mobile users. [44] In December 2013 an SMS (Short Message Service) based order option was also enabled [28]. The SMS option reduced public criticism for the service, even though only 3% of journeys were ordered using SMS [44].

It is worth noting that the SMS syntax might have required some support, as it required using PT stop IDs, which are not commonly known by PT users. A message with the content ”KP 1901 E1129 x3 e20” would order a Kutsuplus journey between stop 1901 in Helsinki and 1129 in Espoo for three people, if there is an option that costs at most 20 euros. Phone support was offered by HSL for finding out stop IDs or other service attributes [28].

The payment side was almost fully coordinated by Ajelo and journeys were paid in advance for all Kutsuplus orders. Payment could not be done using smart cards, even though such a system has been in use for other HSL PT since 2001. Payment was possible only using either a web interface to transfer money to a virtual wallet, or through the customer phone bill if using SMS ordering.

Order using SMS

1. Find out relevant stop IDs for journey and decide a price limit.
2. Send SMS with correct syntax, receive journey details as response.

Order using WWW

1. Sign in to Kutsuplus using a web browser.
2. Ensure you have money in your wallet, transfer funds if needed.
3. Select your origin and destination from a map, knowing addresses or stop IDs may help.
4. Select a journey suggestion after comparing price and details.

Figure 2.6: Options for placing a Kutsuplus order

The two ways in which Kutsuplus orders could be placed have been summarized in Figure 2.6. The service could be accessed by everyone who could use a browser with an online bank service, or had an eligible mobile service provider for SMS ordering. Still, both options were likely cumbersome for a spontaneous first-time user, as users either had to register to an online service featuring a virtual wallet, or learn to use the SMS syntax.

The technical limitations in payment and the lack of a native mobile application were considered the most significant oversights according to HSL customer surveys. HSL recognized the need for a mobile application back in 2011, but even though they created a working prototype, the application was never released to customers. [44]

2.4.3 Service specifications

Operating hours

The operating hours of Kutsuplus were increased three times during the service [44]. In this thesis, we generally refer to the time period specific operating hours were active as a service phase. These phases are listed in Table 2.2. During the first service phase, the operating window was quite narrow, but during the third and fourth phases, the whole morning rush (MR) and evening rush (ER) were included.

Table 2.2: Kutsuplus service phases

Phase	Operating hours	Phase active
1	09:00 – 17:00	October 2012
2	07:30 – 18:30	November 2012 – October 2013
3	06:00 – 23:00	November 2013 – October 2014
4	06:00 – 24:00	November 2014 – December 2015

Kutsuplus vehicles

The initial pilot started in October 2012 with 3 vehicles, which was increased to 10 during the first weeks, and ramped up to 15 vehicles in November 2013 [44]. Thus, the fleet size remained very small throughout the whole pilot. In 2013 HSL still aimed to increase the fleet size gradually so that by the end of 2015 there would be about a hundred vehicles [35], but this was never realized. Unfortunately, there is no information available on whether the whole fleet was operating or not, so it is not possible to identify specific vehicles.

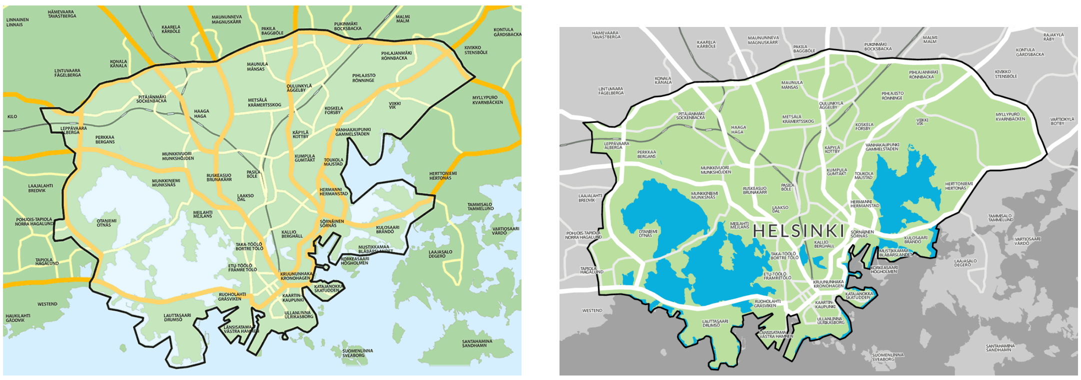
Kutsuplus minibuses were Mercedes Benz Sprinter cars with an Avestark body [94] and at least eight passenger seats [35]. The buses featured seatbelts so they could drive up to 100km/h, while HSL PT buses are exempt from seatbelts their speed is limited to 80 km/h because they feature standing space for passengers and are designed for city use [70, 71]. In practice the road network for the whole Kutsuplus area may be considered to be an urban area, where speed limitations are in practice at most 60km/h, with some exceptions where highway parts enable driving up to 100km/h [84, 87], this means that Kutsuplus did not have to drive slower than private cars.

The vehicles used were of especially high quality and comfort. In addition to displaying real-time passenger specific journey information about the expected time of arrival, buses featured Wi-Fi, air conditioning, rear view cameras, laptop connectors, cushioned seats, curtains, and carpets [35].

Service area

The initial Kutsuplus service area covered eastern parts of Espoo and large parts of Helsinki within the ring road one. Lauttasaari was added to the service area in early 2013, a part of Herttoniemi and Mustikkamaa in summer 2013. Itäkeskus, Myllypuro, and eastern Tapiola were added at the beginning of 2014. In October 2015, the service area was expanded in Tapiola, Vallikallio, Pukinmäki, Malmi, Roihuvuori, Herttoniemi, Herttoniemenranta, and Kalasatama. [44]

The service area from spring 2013, when the campus pilot had recently ended, may be seen in Figure 2.7a. By summer 2015 the area had expanded especially near the eastern and western edges, shown in Figure 2.7b. For a more complete approximation of the realized Kutsuplus service area see Figure 3.1b, which is based on the locations of all stops used in the journey data available. In practice, Kutsuplus operated in significant parts of Helsinki and eastern Espoo, but not in any other part of Espoo or Vantaa. The northern and eastern Helsinki region were also not covered.



(a) Spring 2013 (HSL kutsuplus.fi, 2013)

(b) Summer 2015 (HSL kutsuplus.fi, 2015)

Figure 2.7: Kutsuplus service area

The Kutsuplus service area was in practice spatially so small that it is at worst SAVU IV, but mainly SAVU I and II, rarely III [31, Figure 4], meaning locations should always be accessible with PT using transfers. The area contains the main HMR college campuses in Otaniemi, Leppävaara, Helsinki center, Töölö, Arabia, Viikki, and Meilahti. But it is evident that Kutsuplus was very strongly an urban service, as there was no service to scarcely populated peripheral areas.

The ring rail line was the most significant PT infrastructure change during the Kutsuplus pilot. The rail line did not affect the Kutsuplus service area, because Vantaa was not part of the Kutsuplus service area.

Service classes and pricing

The pricing of Kutsuplus changed multiple times during the pilot, but it was always based on a static base price with additional pricing per kilometer. As the journey was paid in advance the pricing per kilometer was based on approximating a direct route, so customers were not billed extra if the bus deviated from the direct route to serve other customers. For the whole pilot, Kutsuplus included a group discount of 20% for 2 passenger bookings, 30% for 3 passenger bookings, 40% for 4 passenger bookings and 50% for bookings with 5 passengers or more.

Economy and Fast service classes were used to provide customers varying degrees of flexibility. Though no clear LoS was promised, it is implied that Economy customers were served less efficiently than Fast customers. For the final year of service the service, classes were no longer used, but a midday discount of 20% was implemented to increase the demand for daytime travel [44].

Classes and pricing are summarized in Table 2.3. Pricing information has been sourced from HSL board meetings and previous research. [25, 26, 30, 36, 98]

Table 2.3: Kutsuplus pricing

Price active		Kutsuplus		Kutsuplus economy		Kutsuplus fast	
		Base (€)	Per km (€/km)	Base (€)	Per km (€/km)	Base (€)	Per km (€/km)
01.10.2012 – 07.02.2013	*	1.50	0.15	-	-	-	-
08.02.2013 – 10.03.2013	*	1.88	0.19	1.50	0.15	-	-
11.03.2013 – 02.04.2013	*	1.88	0.19	1.50	0.15	2.63	0.26
03.04.2013 – 17.11.2013		3.50	0.45	2.80	0.36	4.90	0.63
18.11.2013 – 11.01.2015		3.50	0.45	2.80	0.36	-	-
12.01.2015 – 31.12.2015	+	3.50	0.45	-	-	-	-

* part of the closed campus pilot
+ 20% discount from 10AM to 2PM

2.4.4 Previous research on Kutsuplus

The final report by HSL provides an overview for project background, key figures, and fiscal details [44]. There has also been research relating to operational and policy level analysis of the pilot, which provides recommendations for future potential on-demand transport services [62].

Post-discontinuation of Kutsuplus the perspectives of users and non-users of the service have been inspected using a questionnaire [98], which we will consider next. There was a total of 1440 respondents out of whom 939 used Kutsuplus actively until it was shut down, 90 who discontinued use at some point and 390 who never tried Kutsuplus. So a total of 1029 respondents used Kutsuplus at some point of the service.

From the questionnaire results, some of the most prominent reasons for the 1029 respondents to use Kutsuplus were in a descending order of responses (1727 selections in total, multiple choice question):

1. Low cost compared to taxi (529 responses, $\approx 51\%$)
2. Fast travel choice compared to PT (516 responses, $\approx 50\%$)
3. Lack of good PT connection (379 responses, $\approx 37\%$)
4. Easiness of ordering a trip (204, $\approx 20\%$)
5. Other (132, $\approx 13\%$)
6. Lack of parking spaces and other problems with using personal car (99, $\approx 10\%$)

These results are in line with what was defined by HSL as an important goal for the service [44]: providing an alternative transport mode to private cars.

20% of the respondents implied the ease of ordering a trip was a significant factor, even though ordering a trip was defined as cumbersome in the Kutsuplus final report [44]. Still, 20% is low if we consider that the question enabled choosing multiple options and all who answered the question were Kutsuplus users who took the time to answer a questionnaire after service shutdown. As most people (939 out of 1029 who tried the service) continued using Kutsuplus it is likely they got used to the service, the wallet system or SMS syntax likely mainly slowed down first-time use.

The questionnaire [98] gathered information on realized journeys endpoints, customer age, income and trip purpose, but we have no reliable way of verifying the authenticity of this information, or to reliably combine this information to the journey data used in this thesis (Section 3.1). Still, we will compare the resulting distributions and spatial demand characteristics of this thesis to those obtained through the questionnaire [98].

A significant advantage of Kutsuplus over taxis was the possibility to serve a higher amount of trip kilometers with less vehicle kilometers, by picking up multiple passengers heading in the same general direction [3]. Future targets for vehicle kilometers were reported after the project was shut down, but no data on realized efficiency per vehicle kilometers has been reported, even though the number of trips per vehicle hour was on the rise [44].

Differences in pricing seem to have caused noticeable temporal demand shifts from rush hours to the midday, when comparing the temporal demand from 2014 to 2015 [62]. On the other hand, the Fast and Economy service classes were not based on real differences between service levels [62], thus it is possible that the Fast class did not actually provide a faster journey outside of rush hours. Monetizing high demand with higher fares could work better for shifting demand away from peaks hours [62]. As the potential to pay for a higher quality service is something often overlooked [60], further potential effects of this will be considered in this thesis.

Still, a significant limitation for research is the short duration of the pilot. For example, the Fast service class was used quite briefly (Table 2.3). Even though popularity was quickly increasing, behavior change requires extended periods of time, especially as on-demand minibus services do not have a well-established niche [62]. The high initial fleet size required time for the market (customers) to catch up to service capacity [92]. Though it is not evident that the service would have been profitable, the amount of subsidy per journey could potentially have been much less if fleet-size had been increased so that each bus operated at high capacity [92].

The need to perform quantitative spatial and temporal analysis on the Kutsuplus journey data has been recognized [62, 98]. Still, this thesis is the first to study realized Kutsuplus journeys and their combined spatial and temporal characteristics in an open fashion.

Chapter 3

Data

In this chapter, we describe the primary data resources used in this thesis. First the Kutsuplus journey data set and performed pre-processing is introduced. Second, the General Transit Feed Specification (GTFS) data of HSL PT operations is introduced. Finally, the HSL HELMET 2.1 demand model and PT demand data for the MPH (Morning Peak Hour), DH (Daytime Hour), and EPH (Evening Peak Hour) is detailed.

3.1 Kutsuplus journey data

The Kutsuplus journey data set is courtesy of Split Finland Oy (formerly Ajelo Oy) and HSL. The author received the data in a Microsoft Excel file where one row details one journey made using Kutsuplus.

In total, there are 83,978 journey entries, taking place during January, March, June, July, August, October, and December. Data for other months was not made available. During 2015, a bit under 100,000 journeys were in total made using Kutsuplus, compared to around 70,000 during 2014 and 15,000 during 2013 [44]. Thus, the available data set accounts for approximately 45% of all Kutsuplus journeys. Fortunately, the months are representative of a full calendar year with one month for spring, three for summer, one for fall and two for winter. Thus, the data can be considered a representative sample of all Kutsuplus journeys.

The data set includes information on order, departure, and arrival time, stops used as journey endpoints, and journey price. The full list of the 13 data fields available have been listed in Table 3.1.

Age information is not available during the campus pilot, which ended on the 3rd of April 2013, but mostly for journeys taking place from June 2013 onwards. Missing service class information is interpreted as travel with the

Table 3.1: Fields in Kutsuplus journey data

Field name	Data type	Description
tripAcceptTime	Time	Time customer accepted journey.
earliestPickupTime	Time	(Assumed) Pick up approximation given to customer.
numberOfPassengers	Integer	Number of passengers on journey.
municipality	String	(Assumed) Optional customer home region.
ageGroup	String	'0-6','7-17','18-29','30-44','45-64','over 65'
paymentMethod	String	'AJELO_WALLET', 'SHARED_WALLET', or 'SMS'
tripPrice	Integer	Total journey price in cents
orderStatus	String	'PickedUp' or 'NoShow'
serviceClass	String	'Säästö','Pika','Normaali' (Economy,Fast,Normal)
pickupStop	String	HSL long or short ID, needs parsing
deliveryStop	String	HSL long or short ID, needs parsing
pickupTime	Time	Time Kutsuplus picked up customer
deliveryTime	Time	Time Kutsuplus delivered customer
directRideTime	String	(Assumed) Optimistic journey duration by routing

default mode active.

Information that could be reliably used to match trips to a specific user has been removed for privacy reasons. Thus, user specific inspections are not possible with this data set.

Pre-processing

To avoid biases in analyzes due to unrealized journeys and erroneous, missing data, the following entries were removed from the data set:

- 1,554 journeys have customer no-show
- 99 journeys have a duration of 0 minutes
- 21 journeys have no delivery time specified
- 14 journeys took over 2.5 hours (even days), which seems unbelievably long

After removing the 1,688 unreliable entries there are 82,290 journeys available. The 82,290 journeys are used in all the computations of this thesis unless explicitly stated otherwise.

Table 3.2: Number of journeys in the provided data set for different time periods of the Kutsuplus service

Phase	Phase active	Journeys made
Operating hours 1 09:00 – 17:00	October 2012	101
Operating hours 2 07:30 – 18:30	November 2012 – October 2013	5135
Operating hours 3 06:00 – 23:00	November 2013 – October 2014	25965
Operating hours 4 06:00 – 24:00	November 2014 – December 2015	51089
Campus pilot	October 2012 – March 2013	1982
Excluding pilot	April 2013 – December 2015	80308
All journeys	October 2012 – December 2015	82290

The pick up and delivery stops were given in 7-digit codes for October 2012 and in 1-4-digit codes with possible letter prefixes for the other months. These formats are specified, maintained, and used by HSL to identify PT stops. HSL provides open access to PT stop data through an online web interface [18]. The 7-digit code is a unique ID for stops, while the short IDs are used for more customer facing notation.

HSL provided a data dump of their PT register from the 20th of February. This data was useful for recognizing specific stop IDs, payment zones and operational details. HSL kindly assisted in deducing that stops E1163 and H1800 in the data set were nowadays represented by E1202 and E1986. H1800 was moved to the Espoo side of the Helsinki-Espoo municipality border, but the pricing zone remained in Helsinki per PT register data.

Basic journey numbers for various time intervals of the journey data are visualized in Table 3.2 for different Kutsuplus service phases and in Table 3.3 for different service months. The monthly journey numbers in Table 3.3 correspond roughly to the proportions of PT journey numbers published by HSL [32]. Especially, there is a corresponding decline in Kutsuplus journey numbers in July of each operating year, which is not surprising as July is the summer vacation month in Finland.

Table 3.3: Kutsuplus monthly journey numbers

Month	2012	2013	2014	2015
January	-	572	2888	6958
March	-	943	3417	7537
June	-	697	3484	5833
July	-	363	2725	3897
August	-	914	4574	5759
October	101	1280	6989	7228
December	366	1888	7279	6598
All	467	6657	31356	43810

3.2 General Transit Feed Specification (GTFS) data

The General Transit Feed Specification (GTFS) is an open data format for public transportation schedules and associated geographic information [12]. A GTFS feed file is a ZIP file that contains multiple text files, each describing some aspect of PT operations [12]. HSL has distributed GTFS data dating back to February 2013 through `https://www.hsl.fi/avoindata/` (accessed July 2017). The files available in the HSL GTFS feed are presented below.

- agency – basic information about PT agency
- calendar – defines recurring service patterns
- calendar_dates – defines schedule exceptions, interruptions, and holidays (optional file)
- routes – defines distinct routes, i.e. specifies PT lines
- shapes – defines rules for plotting routes on a map
- stop_times – defines for each trip the times vehicles are at specific stops
- stops – stop location and ID
- translations – translate labels between Finnish and Swedish (optional extension)
- trips – define trips (”departure times”) for each route

In this thesis, we use GTFS data from September 2015 to analyze PT schedules. For travel time computations, a typical Friday from the feed was selected and thus the effective range considered was from 2015-09-18 to 2015-09-19. A Friday was selected as during Fridays PT may operate slightly longer, but schedules are otherwise identical to other weekdays [34].

This data is from the most active period of Kutsuplus (see 3.3) and provides an accurate representation of the PT network for the Kutsuplus service period. Main changes in the network are with regards to the Vantaa bus line and the Ring rail line, which did not collide with the Kutsuplus service area.

Closer analysis showed that all GTFS data from 2013 to 2015 featured roughly the same number of missing stops, most of which were Kutsuplus virtual stops. There is some variance in which stops are missing, but going through the stops it seems apparent to the author, that even if stop codes change, stops exist roughly in the same places, with only cosmetic service level changes. Thus, the decision to use 2015 data did not require revising.

3.3 HSL HELMET 2.1 PT demand data

The HELMET model is a passenger traffic demand model for the Helsinki region commuting area, including the HMR and nearby provinces. The model has been created by HSL and provides a rough polygonal model for the origin-destination demand of transportation. [20, 41]

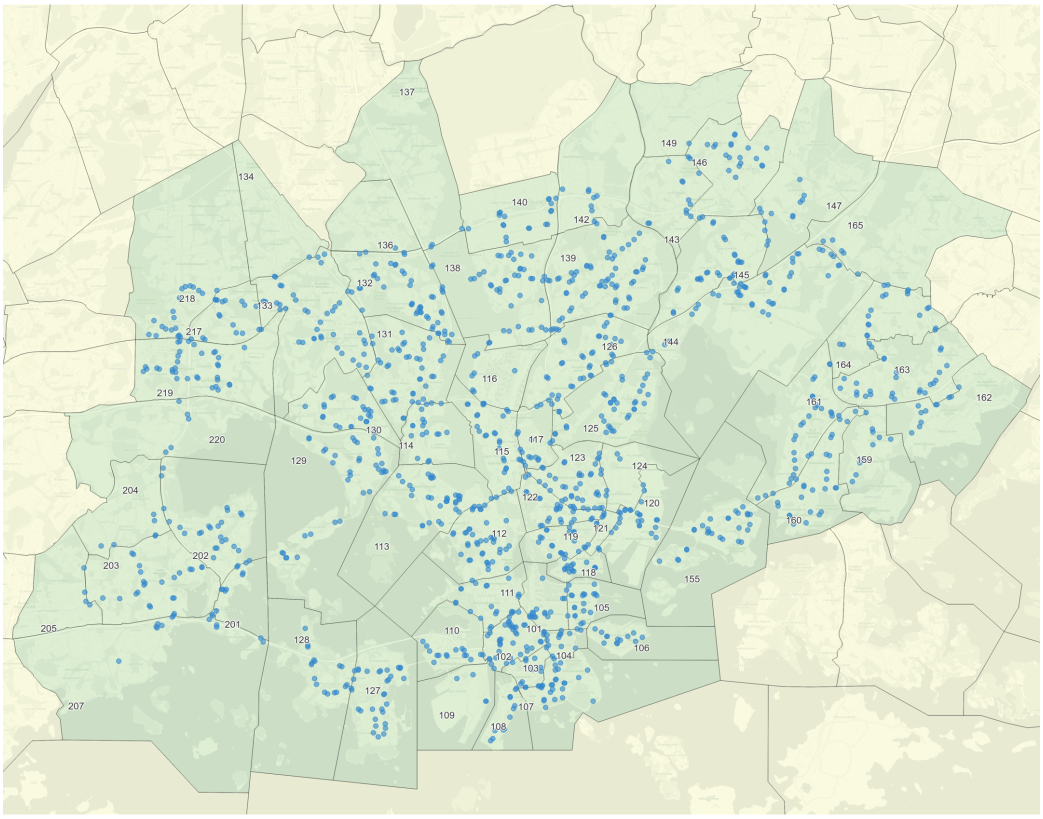
The original HELMET model is based on the HEHA 2007–2008 traffic survey by HSL, where travel behavior of the Helsinki region commuting area (HMR was investigated [20]. An upgraded version, the HELMET 2.1 demand model, was completed in spring 2014 [41]. The upgraded model included multiple re-estimates for traffic flows, especially through the HEHA 2012 survey. The survey was conducted as a form of travel diary, where individual travel during a single day between Monday and Thursday was followed. For more information about HEHA 2012 see [27].

Overall, the HELMET model divides the full HMR to 500 prediction zones (ENN, ennustealue), out of which many are outside the Kutsuplus service area. There are usually multiple placement zones (SIJ, sijoittelualue) within one prediction zone. For example, the placement zones (SIJ) 1000–1274 representing Helsinki, correspond to prediction zones (ENN) 101–174. HSL uses the HELMET model to approximate traffic flow demand for the prediction zones. The more finely divided placement zones are used by HSL to compute travel times, distances, and costs between different areas. [41] The polygonal region division for the Kutsuplus service area is visualized in Figure 3.1a and Figure 3.1b.

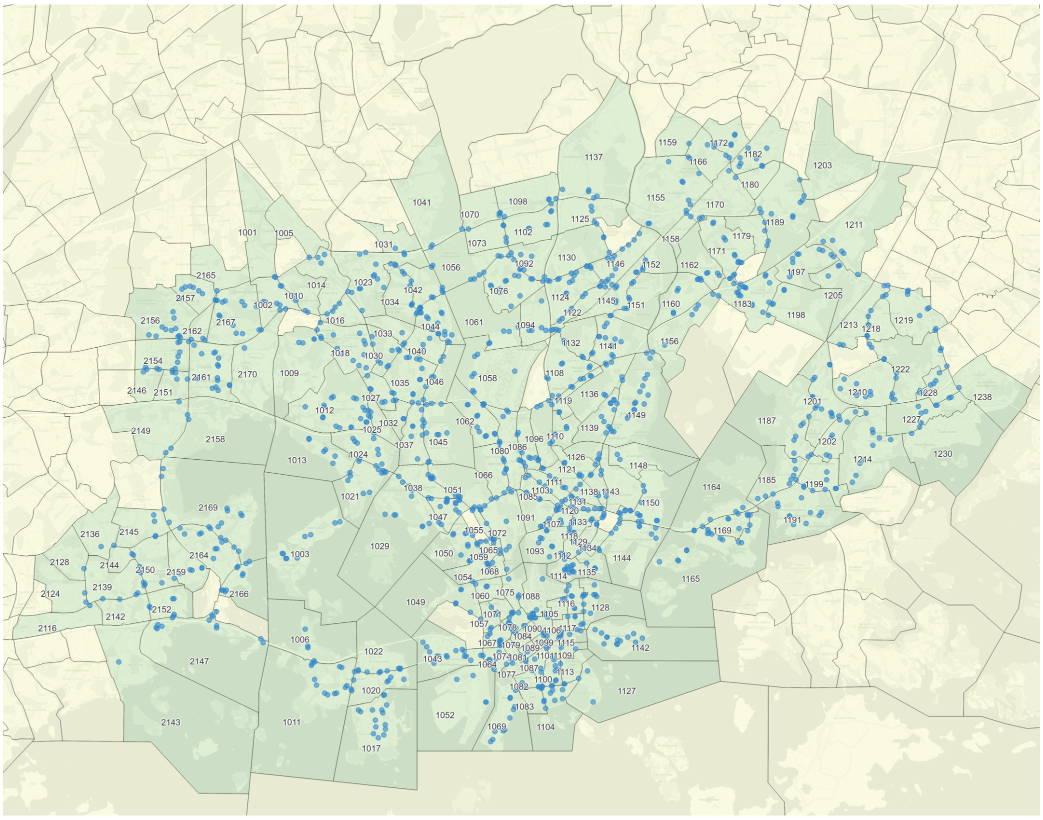
Especial points of interest in the HELMET model are journeys starting during the Morning Rush (MR) 06:00-08:59, Daytime Traffic (DT) 09:00-14:59 and the Evening Rush (ER) 15:00-17:59. These periods attempt to capture distinct demand trends for commuting and daytime journeys. For each of these periods a one-hour interval is defined to represent transport mode specific traffic during the intervals. Morning Peak Hour (MPH) and Evening Peak Hour (EPH) are defined as the one-hour interval during which respectively most MR and ER journeys start for each mode. The Daytime Hour (DH) is defined as the number of journeys during DT divided by six. [41].

In this thesis, the HELMET 2.1 model PT demand data is used to help characterize Kutsuplus demand and to compute reference PT journeys (Chapter 4). In addition to the polygonal divisions in a GIS format, HSL has kindly shared PT demand data of HELMET 2.1 in a CSV-like format for the MPH, EPH and DH.

MPH, EPH and DH demand based on this data is shown in Figures 3.2, 3.3 and 3.4 respectively. Some clear trends are visible for the different periods. During the MPH areas in the city center and other well-known business locations like Pitäjänmäki are clearly highlighted as destinations. MPH origins are mainly in the periphery, where people presumably live. During EPH the trend is largely reversed, but more spread out, likely due to increased amount of after work activities. For DH, the number of journeys seem to form a sort of middle ground between MPH and EPH, with some cross-traffic patterns.

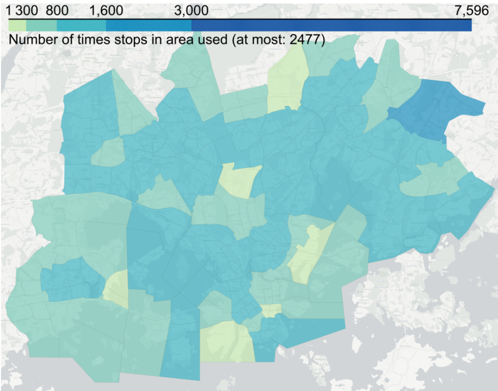


(a) Prediction zone (ENN) polygonal division

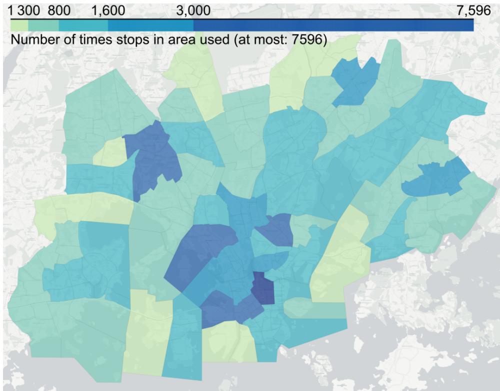


(b) Placement zone (SIJ) polygonal division

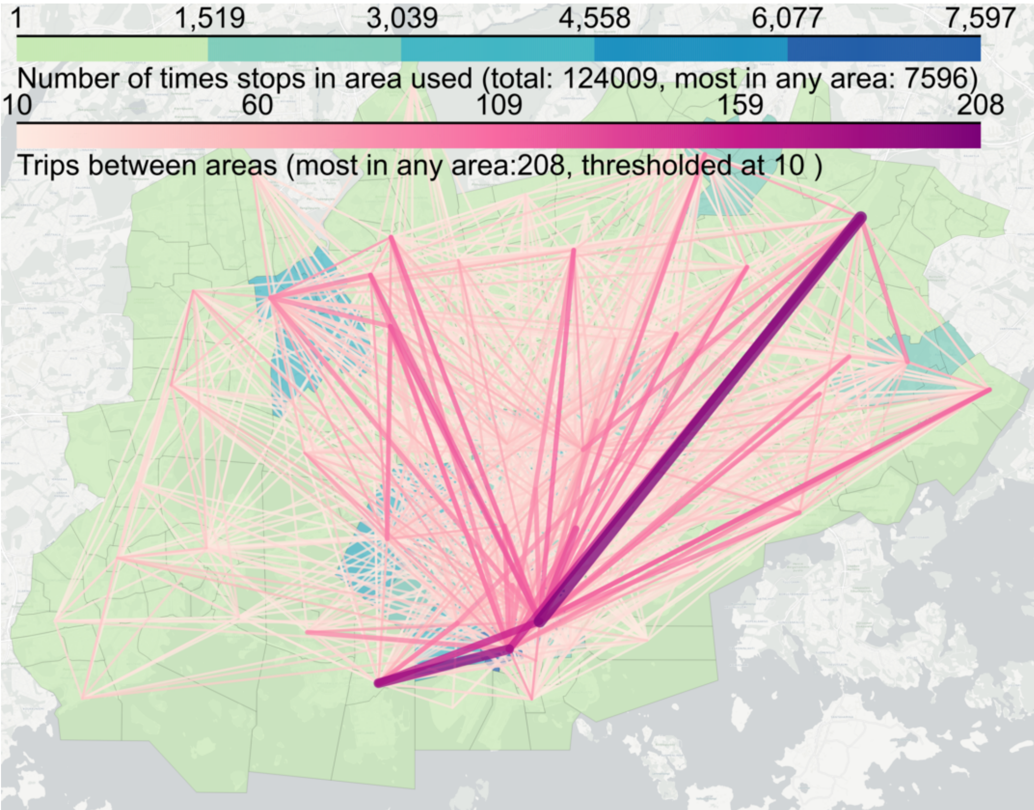
Figure 3.1: Kutsuplus stops from journey data visualized on the polygonal division of the HELMET 2.1 model. Polygon IDs are written on each polygon. Background map: © OpenStreetMap contributors, © CartoDB.



(a) MPH demand (origin)

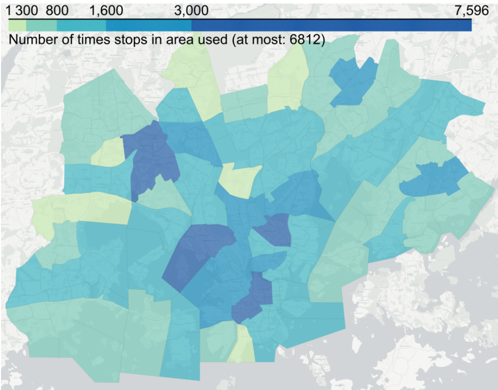


(b) MPH demand (destination)

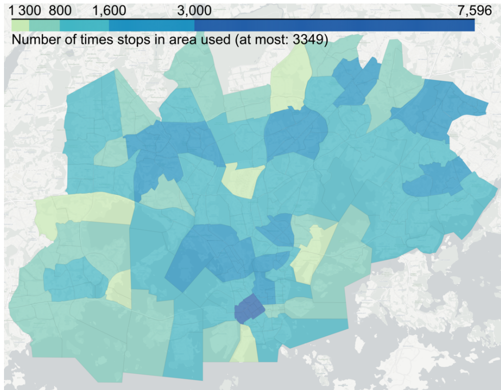


(c) MPH demand (destination), demand lines thresholded at 10 journeys

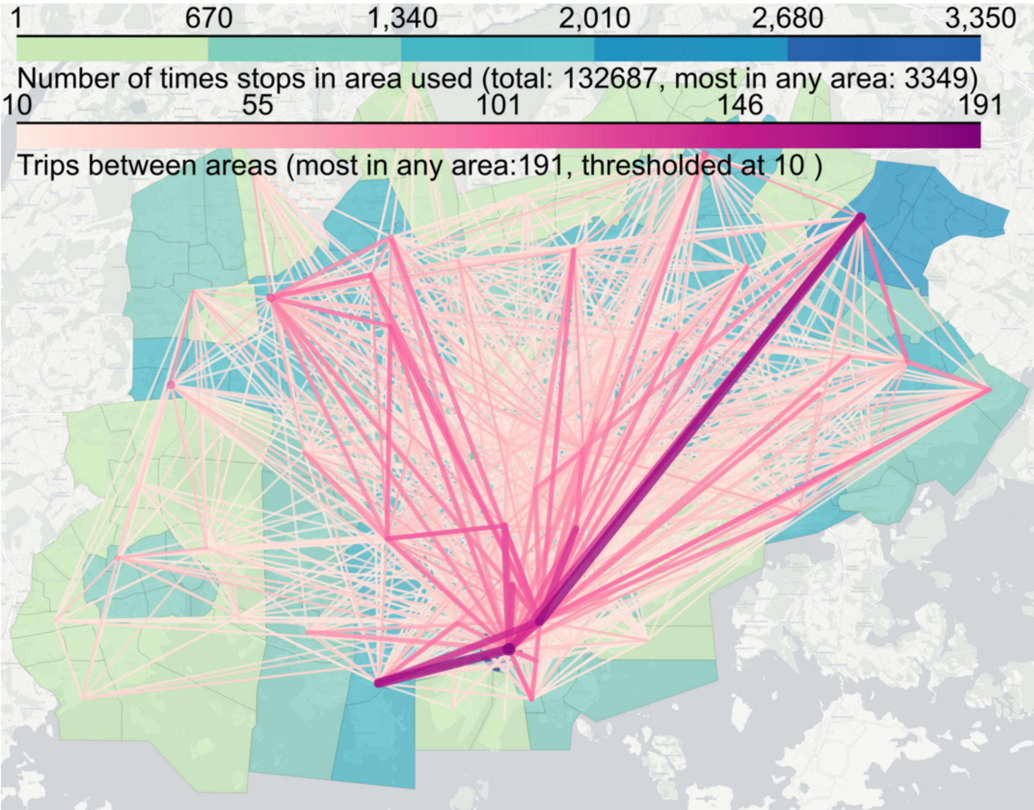
Figure 3.2: HSL MPH (07:15–08:14) demand, on prediction zone (ENN) polygons within the Kutsuplus service area. Background map: © OpenStreetMap contributors, © CartoDB.



(a) EPH demand (origin)

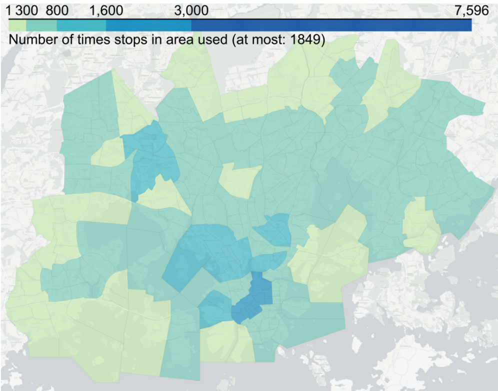


(b) EPH demand (destination)

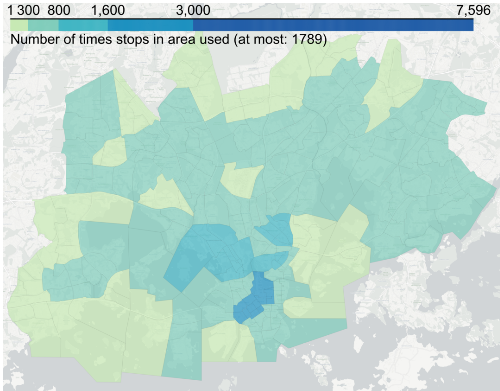


(c) EPH demand (destination), demand lines thresholded at 10 journeys

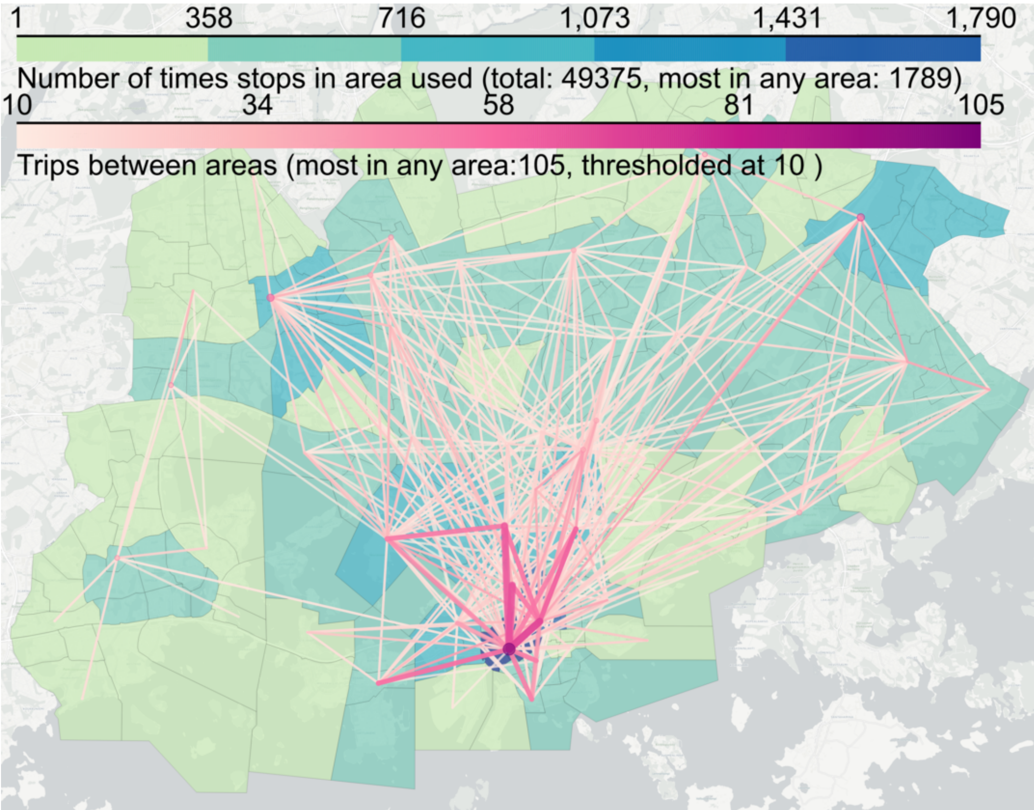
Figure 3.3: HSL EPH (15:30–16:29) demand, on prediction zone (ENN) polygons within the Kutsuplus service area Background map: © OpenStreetMap contributors, © CartoDB.



(a) DH demand (origin)



(b) DH demand (destination)



(c) DH demand (destination), demand lines thresholded at 10 journeys

Figure 3.4: HSL DH demand, on prediction zone (ENN) polygons within the Kutsuplus service area. Background map: © OpenStreetMap contributors, © CartoDB.

Chapter 4

Methods

In this chapter, we first present general journey distance, duration, and price considerations. Second, we present how journey alternatives using other transport modalities are computed. Third, we present how we generate PT specific reference journeys. Finally, we outline the specific technological tools we use for data analysis and visualization.

4.1 General

For journey distances, this thesis considers journeys between two PT stops. In practice parking solutions, bike storages or the real origins of travelers were seldom at PT stops. But as there is no straightforward way to approximate where Kutsuplus orders were made or the route Kutsuplus drove, we will consider the Euclidean distance between stops. We compute estimates for distance driven and walked through routing of alternative travel modalities, but when considering differences between Kutsuplus and other modes only the Euclidean distances ensure compatibility.

For journey durations, we focus on In-Vehicle Time (IVT) as the Kutsuplus journey data is not suitable for doing Out-of-Vehicle Time (OVT) analysis due to lack of information on walking distances to PT stops. Parking and the wait environment considerations will correspondingly also be ignored. In practice journey duration is analyzed as a scalar value for modes other than PT, and through multiple scalars for PT, to enable considering a lenient departure window. As an OVT consideration for Kutsuplus we consider the amount of waiting from customer order and estimated pick up time against the time a PT user would wait on average when departing spontaneously.

In general, prices will be considered as total journey prices, not per passenger. Total prices enable clearer comparisons to the Kutsuplus prices, which are paid from one account. Some travel forms like taxis also offer discounts for multiple passengers.

4.2 Computing alternatives for Kutsuplus journeys

This section will describe how journey alternatives are computed for Kutsuplus journeys. The modes we consider are private car, walking, cycling, taxi, Uber, and PT. For personal modes of transport only marginal costs are considered, so both walking and cycling are regarded as free, while car pricing considers only fuel costs. Taxi and Uber will use journey durations and distances estimates obtained through private car routing.

Because taxi may exclusively use some bus lanes in the HMR, with professional drivers likely knowing the most optimal routes, it may enable smoother passage through the most congested regions of the city, thus effectively eliminating waiting. Thus, we consider unweighted private car journey durations as the reference for taxi journey durations. As using bus lanes is limited to taxis, we assume Uber usage corresponds to congestion weighted private car durations.

We will consider journey alternatives in the following order. We first introduce computations for walking, cycling, and driving routes that rely upon the Google Distance Matrix API. Second, pricing for private cars. Third, pricing for taxi. Fourth, pricing for Uber. Finally, we introduce pricing and route computations for PT, which also consider the effects of transfers and different limits on walking legs.

The aspects considered for each mode have been summarized in Table 4.1. A flow chart on how the Kutsuplus data set is processed and enriched with information about journey alternatives is visualized in Figure 4.1. Preprocessing of the data was elaborated on in Section 3.1.

Table 4.1: Aspects of journey alternatives summarized.
GDM refers to the Google Distance Matrix API [11]

Mode	Price	Routing	Routing period	Other considerations
Bike	0	GDM	9/2017	-
Walk	0	GDM	9/2017	-
Car	Computed	GDM	9/2017	Congestion and without
Uber	Listed	GDM (Car)	(9/2017)	Congestion weighted
Taxi	Listed	GDM (Car)	(9/2017)	Congestion ignored
PT	Listed	gtfspy	9/2015	Transfers, walk limits

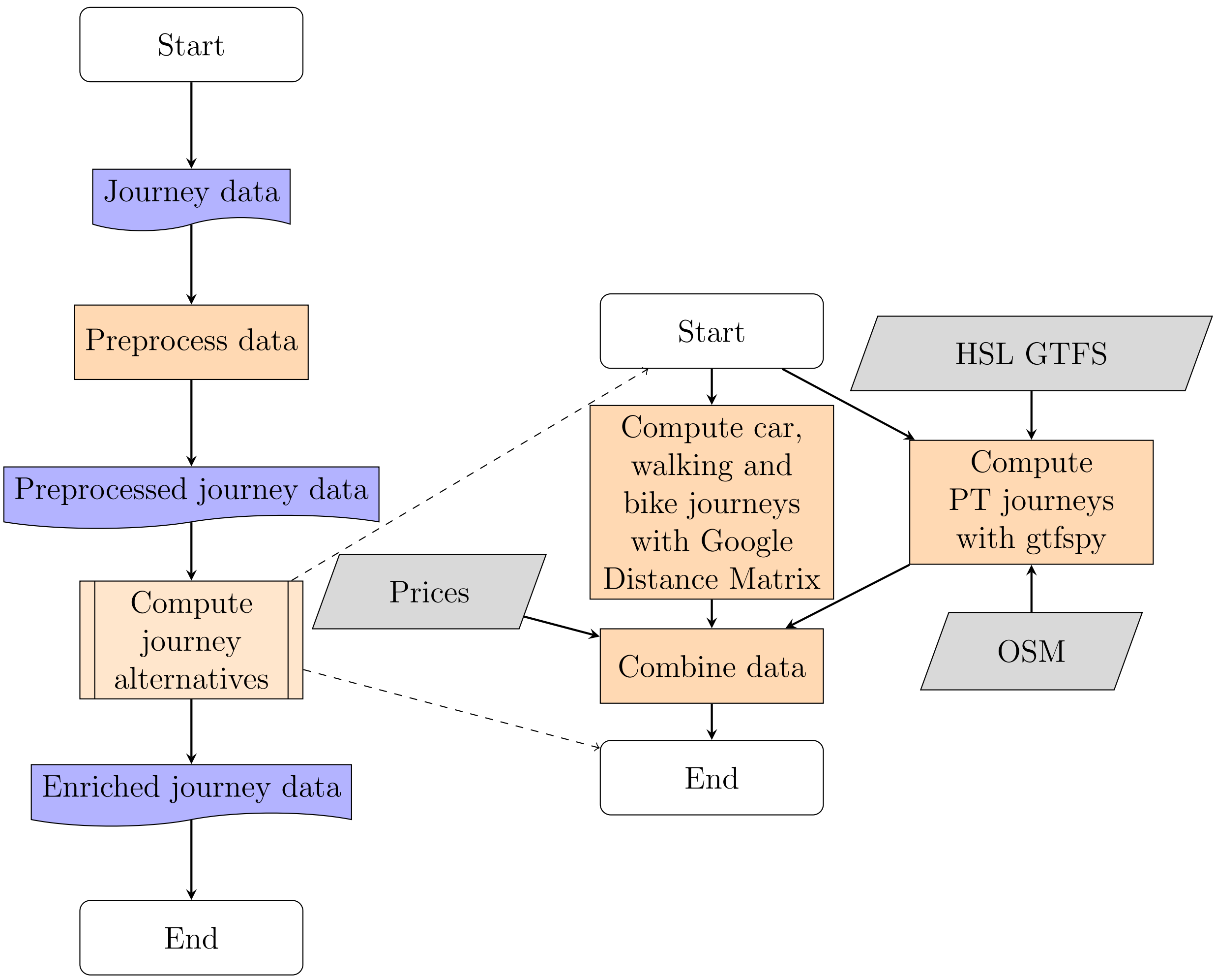


Figure 4.1: Flow chart on how the Kutsuplus journey data is enriched with journey alternatives

4.2.1 Computing travel times and distances for car, walking and cycling

We use the Google Distance Matrix API [11] to compute private car, walking and cycling route information between Kutsuplus origins and destinations as journey distances and durations. We chose the API because Google Maps provides a globally well established and accurate solution for planning journeys with huge amounts of historical data to support service reliability.

We use weekdays of September 2017 as the time period for the computations as the Distance Matrix API requires a future date. September should represent an average working month quite well. For journey start times, we use the same hour and minute Kutsuplus journeys featured for customer pick up.

For private cars, what makes the Distance Matrix API especially tempting is the possibility to consider traffic congestion, based on historical average information. Thus, we consider Kutsuplus journey alternatives for private cars with both congestion weighted and non-weighted estimates.

For walking and cycling, the API appears to approximate walking speed at roughly 5km/h (around 1.4m/s), and cycling speed at roughly 15.5km/h (around 4.31m/s). Corresponding values have been reported in [4] and [66]. The API accounts for route specific features like intersections when computing journeys, likely based on historical GPS data, but specifics are unknown.

4.2.2 Private car pricing

Owning a private car entails various fixed costs like permits and annual vehicle inspections, but when comparing car use to other modes this thesis will consider only marginal costs in the form of fuel price. While the fixed costs may certainly make up a large portion of using a car it is not reasonable to assume people give up on their private cars because an attractive on-demand PT pilot becomes available, thus we assume marginal costs are the most important measure to quantify for future mode choice considerations.

To approximate the fuel price for private cars we look at statistics from Kutsuplus operating years. Effectively the fuel price for each journey is computed as

$$price = euro/liter * liter_{consumed}$$

Details are provided in Appendix A.

Table 4.2: Taxi prices used in Finland

Price active	Base price (€)	Increased base price (€)	Passengers (€/km)			
			1–2	3–4	5–6	over 6
01.07.2012 – 30.6.2013	5.70	8.80	1.48	1.78	1.92	2.07
01.07.2013 – 30.6.2014	5.36	8.18	1.38	1.66	1.80	1.94
01.07.2014 – 30.6.2016	5.36	8.18	1.41	1.70	1.84	1.98

Table 4.3: Uber prices used in Finland since November 19th 2014

Service	UberBLACK	UberPOP
Base price (€)	5.0	2.0
Minute price (€/min)	0.4	0.2
Kilometer price (€/km)	1.9	1.0
Minimum price (€)	12.0	4.0

4.2.3 Taxi pricing

When Kutsuplus was active, maximum taxi prices were agreed upon annually by the Finnish government [73–76] and it was generally acknowledged that the maximum price is in fact also in practice the minimum price for short taxi trips within the HMR [77]. Below is an aggregated table combined taxi prices for each corresponding operating period of Kutsuplus. It is worth noting that taxi may also charge extra for waiting (i.e. late passengers, driving on very congested streets, etc.), but here we assume that such journeys are in general unlikely.

4.2.4 Uber pricing

Prices for the service are depicted in 4.3, based on information retrieved from the mobile application. As opposed to taxis, Uber prices do not increase with passenger amounts while taxi prices do, but Uber pricing may be increased without a hard limit by high demand. Unfortunately accurate data regarding surge pricing is not readily available, so we assume prices were at base level, even though we have noted events like New Year's Eve may cause significant surges (see Section 2.2).

4.2.5 Public transport journey alternatives

Whereas computing routes for cars is relatively straightforward, for PT we need to consider timetables and transfers to efficiently reach a destination [1]. Because using Kutsuplus had to be based on precognition, i.e. planned beforehand, we consider PT options for a departure time interval. We define our travel window so that departure may happen within 30 minutes before or after the Kutsuplus pick up time. Arrival at latest 120 minutes after the Kutsuplus pick up time. Temporal distance profile is the formal name used when referring to the journey durations measured for a travel window [8, 58]. For denoting temporal distance, we use τ. Effectively no journey within the service area should take over two hours. In the scope of this research vehicle preference considerations are ignored.

We consider only Pareto-optimal journeys in our computations [58]. Pareto-optimality for a journey means that there are no faster options available for a PT user departing at a certain point in time. In addition to the minimum temporal distance τ_{min}, we also compute $\tau_{min_t,b_{min}}$ as the fastest-path journey option in the departure window, which features the least number of vehicle boardings.

For transfers, we use a 3-minute margin as is customary by the HMR journey planner (`http://www.reittiopas.fi/`, accessed July 2017). Because sometimes walking legs might be a faster travel option than using PT, we consider the number of vehicle boardings, rather than transfers. So, if walking is the fastest option a journey would features zero boardings. b_{fast} is the number of boardings needed for τ_{min}, while b_{min} is the number of boardings needed for $\tau_{min_t,b_{min}}$.

PT computations will be performed in a manner that allows a walk between two stops if they are at most 2 kilometers apart, but not chaining multiple walks directly after one another. By decreasing the allowed walking distance, the number of boardings and journey duration effectively increase, as fewer PT options are available. For sensitivity analysis and accessibility, especially with older age groups and special groups in mind, we also consider a walking cutoff of 0.5 kilometers.

We also attempt to quantify PT for spontaneous use. Spontaneous use is inspected through τ_{mean}, which also includes a pre-journey waiting time by considering an average of all fastest-path journey options in the travel window. We denote the average number of vehicle boardings for the fastest-path options in the travel window as b_{mean}. We subtract τ_{min} of the departure window from τ_{mean}, to approximate how much time PT users would lose by not planning their journeys in advance. This value will be compared to how accurate the estimated pick up time of Kutsuplus was.

Connection Scan Algorithm

The Connection Scan Algorithm (CSA), originally in [8] and more recently in [9], enables computing Pareto-optimal journey alternatives for an origin-destination pair. Basically, CSA models PT operations as a temporal network [17], where connection events between stops can be thought of as temporally active links between nodes. [58]

The CSA family of algorithms is conceptually easier than competing methods but still provides good performance in computational time and resources, especially when compared to more general approaches such as Dijkstra's algorithm and A-star [8, 58]. Thus, the computations in this thesis will compute PT journey alternatives for Kutsuplus journeys using an CSA approach.

The CSA algorithm works by first ordering all PT connections in a minimum priority data structure, specifying a destination node to which journey travel times are computed, as well as the routing window start and end times, for which connections between stops will be considered. After this the algorithm goes through each connection in a decreasing order (latest/last first), updating the potential Pareto-optimal journey alternatives for reaching the destination, whenever the journey origin is reached.

The multi-criteria profile connection scan algorithm (mcpCSA) also introduced in [8] effectively has the same gist, but may also consider different number of transfers as a criterion for the Pareto-optimal journeys. Thus, by using mcpCSA, the Pareto-optimal journey alternatives for a journey are computed by both minimizing travel time and considering varying numbers of transfers for the route.

gtfspy

gtfspy (`https://github.com/CxAalto/gtfspy`, accessed July 2017) is an open-source Python package for working with GTFS data. The library enables accessibility analysis using a routing/profiling engine which is based on an adaption [58] of mcpCSA, which was originally described in [8]. The main modification, as presented in [58], enables walking between bus stops, as so called pseudo-connections. This is especially useful as some Kutsuplus stops were not accessible with conventional PT and short walking transfers to different stops are quite common within the HMR.

We use gtfspy to compute Pareto-optimal PT alternatives. In addition to the journey temporal distance in the departure window, we consider the number of vehicle boardings required and different walking cutoffs for each journey alternative.

Computational considerations

If we were to run the modified mcpCSA algorithm for each Kutsuplus journey in turn, computations would take around an hour for each journey. Even if we distributed this to multiple processors, the running time would still be unreasonable. Especially, as different limits for walking require us to recompute gtfspy pseudo-connections between stops, and thus also all PT routing that relies upon them.

Thus, for computational efficiency, the 82,290 Kutsuplus journeys are grouped by destination, resulting in 1,314 routing runs, per the number of unique destination stops. The mcpCSA algorithm routing is run for each destination stop only once per walking distance, and used during the analysis stage to inspect specific journeys with departure and arrival time constraints. Routing is done from Friday 2015-09-18 to Saturday 2015-09-19 using HSL GTFS data detailed in Section 3.2.

Public transport journey features summarized

As the focus of our analysis is on considering journey durations while minimizing vehicle boardings and on considering different limits for potential walking legs, we have summarized the attributes we will compute for each PT journey alternative in Table 4.4.

Table 4.4: PT journey attributes

Measure	Description
τ_{min}	Minimum temporal distance (shortest travel time in departure window)
τ_{min,min_b}	τ_{min} with least possible boardings
τ_{mean}	Mean temporal distance (mean travel time for spontaneous departure)
b_{fast}	Number of vehicle boardings needed for τ_{min}
b_{min}	Number of vehicle boardings needed for τ_{min,min_b}
b_{mean}	Average number of vehicle boardings needed for fastest-path options in departure window
$\tau_{mean} - \tau_{min}$	Time lost waiting for τ_{min} if departure is spontaneously
$\tau_{min,min_b} - \tau_{min}$	Time lost using option with b_{min} instead of b_{fast}

Table 4.5: HSL public transport ticket prices

	From PT driver (€)		Travel card (€)	
Year	Internal ticket	Regional ticket	Internal ticket	Regional ticket
2012	2.70	4.50	1.84	3.47
2013	2.80	4.50	1.90	3.47
2014	3.00	5.00	1.95	3.65
2015	3.00	5.00	2.00	3.88

Pricing

Ticket prices for HSL PT are listed in Table 4.5 [23]. The prices used for comparing PT to other modalities are based on single-journey value tickets purchased with the HSL travel card. The HSL travel card is the de facto and cheapest way to travel using PT. For example, [56] noted that 97% of journeys made were paid using the travel card, which are effectively owned by almost all people using PT. Regional ticket prices are more expensive than internal tickets, whereas Kutsuplus pricing was not affected by municipality borders, thus we will also inspect the portion and amounts of regional trips for Kutsuplus PT alternatives.

Cash prices are provided as reference, but it is worth noting that for active PT users the HSL travel card may also be purchased and used as a time-based ticket. Time-based tickets may be purchased from 14-day validity to up to one year with the day-adjusted price going down for longer intervals. For active PT users, the time-based ticket is generally the cheapest way to travel, but as the journey data provides no way of inspecting user specific Kutsuplus usage only the value-based travel card or cash are plausible reference options. SMS or ticket machines may also be proactively used in PT terminal areas to purchase tickets with a reduced price, but as ticket machines are not widely available and the SMS tickets feature limitations, we only list the price of buying the ticket from the driver with an increased price as reference. Still, with the ease of getting a travel card this thesis only considers travel card value prices for the computations.

4.3 Reference models

One research objective of this thesis is to inspect whether Kutsuplus was used for routes with sub-par PT accessibility. To understand whether Kutsuplus was especially used between such origin-destination pairs, information on PT journeys taking place within the Kutsuplus service area is required. To this end, one reference available is the HELMET demand model, which describes journey amounts between prediction zone polygons (ENN) in the HMR.

The HELMET demand model does not directly answer the question of PT service accessibility, rather it quantifies what kind of journeys are commonly made. Thus, to gain a referenceable measure of accessibility we generate PT journeys based on the most common polygon pairs used as origins and destinations within the HELMET demand model. To gain further insight to potential journey options within the Kutsuplus service area, and to capture also journey options which are uncommon, we also consider a distance distribution based approach for selecting journey endpoints, and a randomized approach. The primary aim of the reference models is to compare the spatial demand and characteristics of the reference PT journeys to Kutsuplus demand and to PT journey alternatives for Kutsuplus. As PT journey characteristics, we will consider the number of boardings, distance, duration, and price.

For each reference heuristic, we sample 10 000 stop pairs and route them for MPH, DH and EPH using gtfspy as presented in Section 4.2.5. In each approach origin and destination prediction zone (ENN) polygons can be the same, but origin and destination stops cannot. Walking legs are limited to 2000 meters, but journeys with a 500-meter walking cutoff will also be generated to enable sensitivity analysis. We will now go through the three sampling heuristics we use: HELMET sampling (HELMET), distance sampling (DS), and random sampling (R). All sampling approaches use replacement.

In HELMET sampling (HELMET), endpoints are sampled using the HSL HELMET 2.1 PT demand data (see Section 3.3) limited to the Kutsuplus service area. The sampling is done so that we assign each possible polygon pair $(i- > j)$ a weight, which is the number of journeys made from i to j, divided by the total number of journeys made in the demand data for the Kutsuplus service area. Using the weighted list, we first select a polygon pair, then an origin and a destination is selected from corresponding polygon at random. HELMET sampling uses the best data available for depicting PT demand in the Kutsuplus service area. Thus, we assume HELMET sampling enables us to consider PT between areas, which have been recognized as high-demand by HSL.

In distance sampling (DS), we use a distance distribution based approach, where endpoints are sampled from all Kutsuplus stops used, so that the Euclidean distance distribution of the sampled stop pairs resembles the Euclidean distance distribution for realized Kutsuplus journeys. Importantly, we use a binning approach to group stops in 100-meter intervals so that stop pairs that are 100 to 199 meters from another form one bin, as do stop pairs that are 1000-1099 meters from another. Binning is used to avoid a bias where stops with an exact Euclidean distance are favored over other potential pairs with a comparable distance. The sampling is done so that after binning all possible stop pairs within the Kutsuplus area, we assign weights to each bin as the fraction of pairs in a bin divided by the total number of pairs. Using the weighted list, we first select a bin with replacement and then a stop pair from within the bin at random. DS enables us to find journeys of comparable length to Kutsuplus PT alternatives. We will use DS to quantify whether journeys of comparable length were comparable also through other journey characteristics.

In random sampling (R), we assign each possible stop pair a weight as one per the total number of pairs. Then, stop pairs are selected at random from all Kutsuplus stops that were present in the journey data. R is intended to work as a baseline method. By considering all PT stops that were used at least once by Kutsuplus users equally, R provides an unbiased way of sampling different PT connections between them.

4.4 Analysis and visualization tools used

In this section, we describe the technical tools and solutions used for visualizing data. For this section, we confirm website availability and use the newest stable versions of tools available for Ubuntu 16.04 and Windows 10 on the 31st of July 2017. As resulting code is domain specific and relies upon the Kutsuplus journey data, we do not share it outside the Complex Systems group of Aalto University.

For processing and filtering the journey data in various ways we largely rely upon Python 3 (`https://www.python.org/`) with the libraries Pandas (`http://pandas.pydata.org/`), NumPy (`http://www.numpy.org/`) and SciPy (`https://www.scipy.org/`).

For drawing plots other than maps we use Matplotlib (`https://matplotlib.org`). We also use parts of the verkko library (`https://github.com/CxAalto/verkko`) for general purpose analysis and visualization.

For visualizing data on maps, we use Folium (`https://github.com/python-visualization/folium`). Folium stores maps as HTML (Hypertext Markup Language) files which enable us to interactively inspect spatial demand and manipulate page elements using HTML and CSS (Cascading Style Sheets). To visualize HTML pages generated by Folium as static images, we first render a high-resolution version of the web page with the headerless WebKit PhantomJS (`http://phantomjs.org/`) and take a screenshot of it. The high-resolution screenshot is downscaled using ImageMagick (`https://www.imagemagick.org`) and losslessly optimized for space using OptiPNG (`http://optipng.sourceforge.net/`). The process of taking screenshots is automated using the test and automation framework Selenium (`http://www.seleniumhq.org/`).

Chapter 5

Results

In this chapter, the results obtained using the data and methods from previous chapters are presented. First, general Kutsuplus characteristics are presented. Second, we present the results from computing different modes of travel against Kutsuplus journey metrics. Third, we consider fare zones, walking, boardings and waiting as PT specific characteristics. Finally, we consider the reference models used to generate PT journeys, by comparing the demand and characteristics of these journeys to PT alternatives for Kutsuplus.

When considering the results please keep in mind that only approximately 45% of all Kutsuplus journeys are available for this thesis.

5.1 Characterization of Kutsuplus journeys

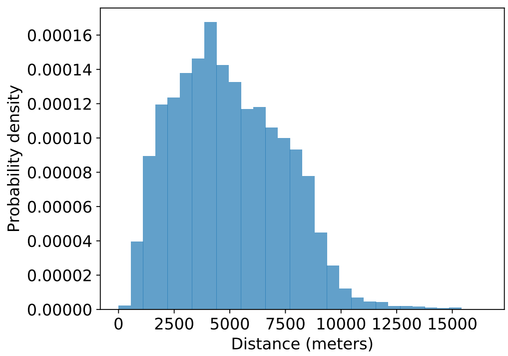
5.1.1 Basic statistics

Table 5.1: Kutsuplus journey data average statistics

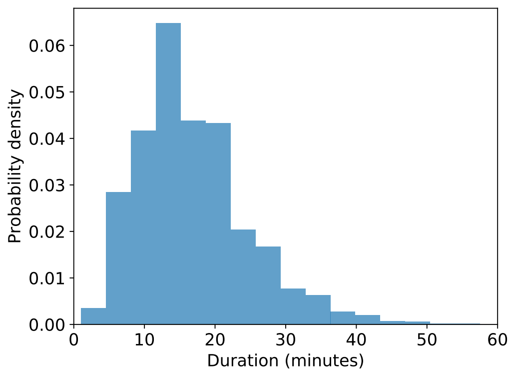
Year	2012	2013	2014	2015	All
Average passengers on journey	1.27	1.24	1.28	1.26	1.27
Average journey price (€)	3.31	5.86	6.40	7.15	6.74
Average journey distance (Euclidean km)	5.43	5.23	5.02	4.90	4.98
Average journey duration (minutes)	20.45	17.36	16.84	16.98	16.98
Average time pick up after estimate (minutes)	2.71	3.98	4.07	4.25	4.15
Average wait from trip acceptance (minutes)	22.44	21.70	19.87	21.44	20.87

Key statistics of Kutsuplus journeys, featuring journey distance, duration, price, wait times, and the number of passengers are presented in Table 5.1. Values appear to correspond to those provided by HSL [44], though the average pick up time after the estimate does seem relatively large.

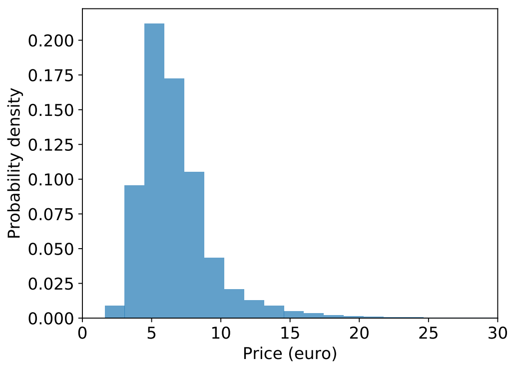
Distributions for journey distance, duration, price and the number of passengers are shown in Figures 5.1a, 5.1b, 5.1c and 5.1d. Most Kutsuplus journeys were less than 10 kilometers long, lasted less than 30 minutes, cost under 10 euro and featured few passengers. There seem to be no notable differences in the distributions if considering more specific service phases, so we show only distributions for all journeys.



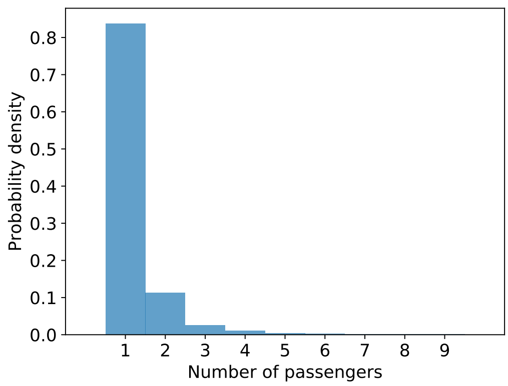
(a) Distance of journeys (meters, Euclidean distance between stops)



(b) Duration of journeys (minutes)



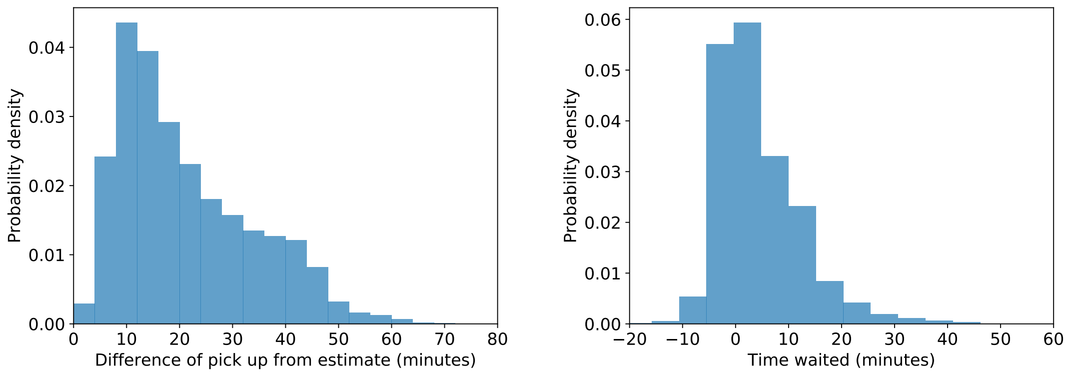
(c) Price of journeys (euro)



(d) Number of passengers on journeys

Figure 5.1: Kutsuplus journey basic distributions (all journeys)

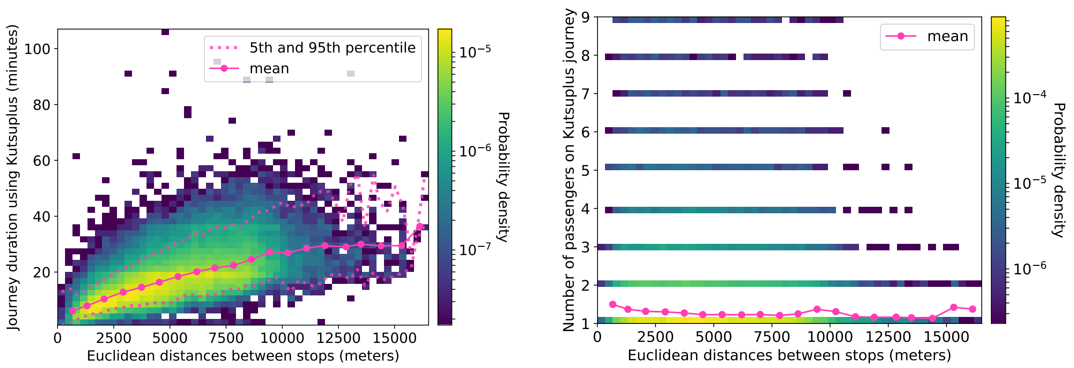
The average time between an order and pick up is visualized in Figure 5.2a, while how punctual pick ups were with regards to estimates given is visualized in Figure 5.2b. While Figure 5.2a shows wait times from order were relatively short, implying Kutsuplus could often be ordered with a quite short notice, the long tail of the distribution in Figure 5.2b is surprising. HSL stated that 35% of pick ups were realized within a +/-30 second range of the given estimate [44], but while this might hold true, the journey data available only has minute level information on pick ups. We note that 10% of journeys were picked up on the estimate minute, while almost 73% of all pick ups were at least two minutes early or late from the estimate. We assume this estimate value was given to customers in order confirmation, but we have not been able to verify this.



(a) Wait time to pick up after placing order (minutes)

(b) How pick up time varied from pick up estimate (minutes)

Figure 5.2: Kutsuplus journey wait time distributions (all journeys)



(a) Journey duration as a function of Euclidean journey distance

(b) Number of passengers on journey as a function of journey distance

Figure 5.3: Heat map distributions for all Kutsuplus journeys

To inspect dependencies between the distributions we have visualized journey distance as a function of journey duration in Figure 5.3a and the number of passengers as a function of journey distance in Figure 5.3b. Journey duration increases as a function of distance as is to be expected, and there do not seem to be any major trends relating to the number of passengers on a journey. Based on long journeys with zero duration visible in Figure 5.3a, there seems to be some noise remaining in the journey data, which is not surprising as the pre-processing of the journey data was not very strict. These outliers are not significant in amount.

5.1.2 Daily variation in temporal demand

We compute temporal peak characteristics for each Kutsuplus service phase by considering the average number of journeys started during each operating day. Day level journey amounts are visualized in Figure 5.4. There seems to be a PT typical peak structure especially during the third and fourth service phases. During the fourth phase, a clear midday peak is also visible, during which pricing was 20% off. During the first two service phases demand was very low.

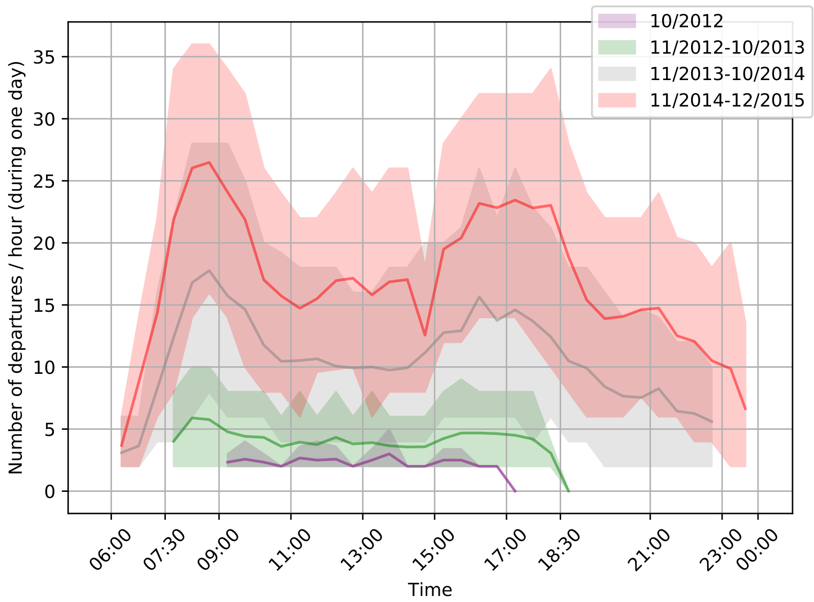


Figure 5.4: Amount of daily Kutsuplus journeys during each service phase. 10th and 90th percentile limited area as background

To enable comparisons to the HSL HELMET 2.1 MPH (Morning Peak Hour) and EPH (Evening Peak Hour) demand data, we identify Kutsuplus MPH and EPH intervals as the most active hours of MR (Morning Rush) and ER (Evening Rush). We use a one-hour interval, so that for each minute we consider the journeys starting then or during the next 59 minutes. DH (Daytime Hour) will be considered as journeys starting between MR and ER. Daily journey amounts using a one-hour sliding interval are visualized in Figure 5.5.

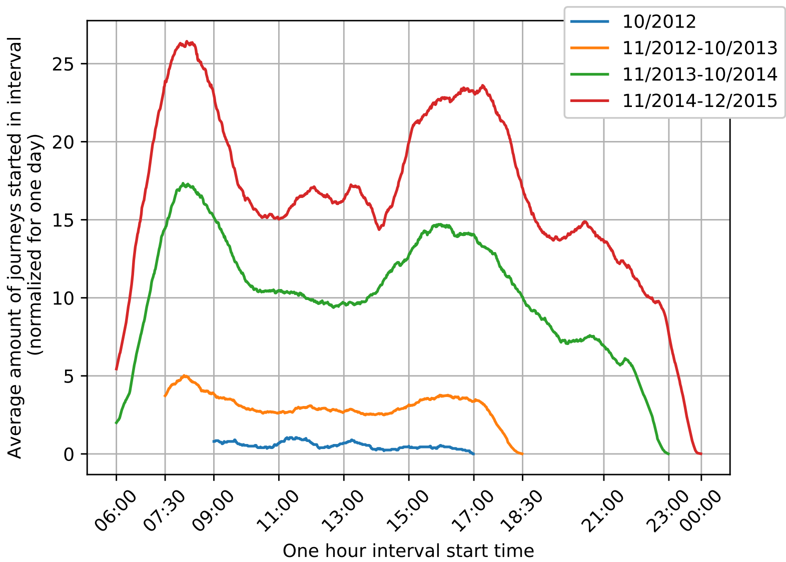


Figure 5.5: Amount of journeys using a one-hour sliding interval

We consider only phases 3 and 4 because they include the full MR. Based on Figure 5.5 we deduce Kutsuplus MPH as 08:00–08:59 and EPH as 16:42–17:41. In Table 5.2 is depicted how large a portion of Kutsuplus trips start during MPH and EPH. All columns except for Kutsuplus are from the HELMET 2.1 demand model [41]. Kutsuplus DH is not shown to avoid potential confusion caused by the limited operating hours of Kutsuplus when compared to HSL PT. We note that Kutsuplus peaks are later than for HSL, possibly due to the more flexible nature of the service and due to the service area being centered close to the HMR center.

Late pick ups appear to be timed during the most active hours of the service per Figure 5.6. Even the second phase suffered from late pick ups, even though usage was low and fleet size comparable.

Table 5.2: Kutsuplus vs. HELMET 2.1 - Peak hour portions (%)

Journey start interval	HELMET PT	HELMET Walk/Bike	HELMET Car driver	HELMET Car passenger	Kutsuplus (Phase 3&4)
MPH 1 07:15 – 08:14	47.45	-	-	-	42.75
MPH 2 07:30 – 08:29	-	54.97	47.11	48.31	48.51
KP MPH 08:00 – 08:59	-	-	-	-	54.83
EPH 1 15:30 – 16:29	45.58	-	37.59	35.49	33.43
EPH 2 16:15 – 17:14	-	37.28	-	-	34.83
KP EPH 16:42 – 17:41	-	-	-	-	35.07

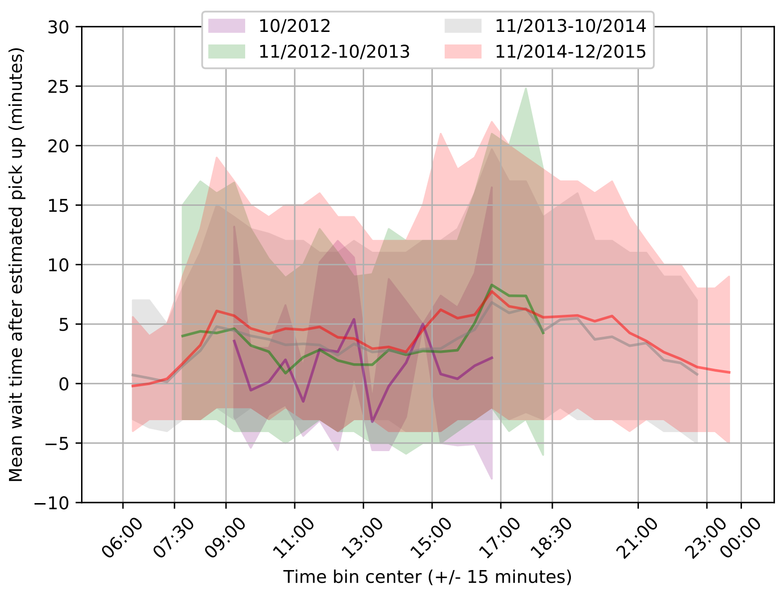
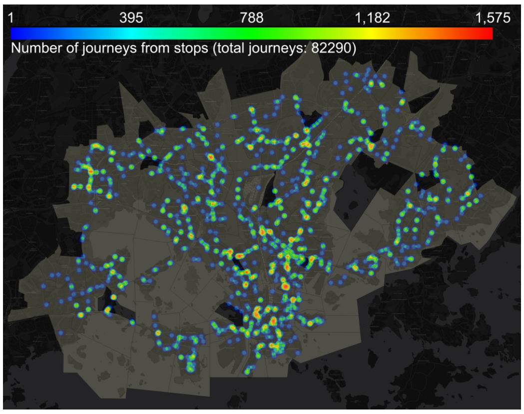


Figure 5.6: Mean wait time for Kutsuplus after estimated pick up time (minutes). 10th and 90th percentile limited area as background.

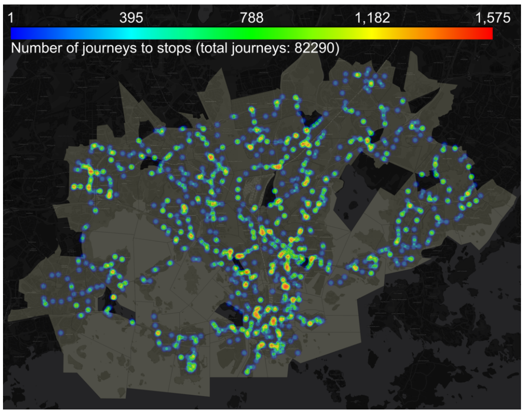
No notable day-level patterns in journey distance, duration, price, or passenger amounts during any of the later Kutsuplus phases could be found, so these plots are not shown.

5.1.3 Spatial demand

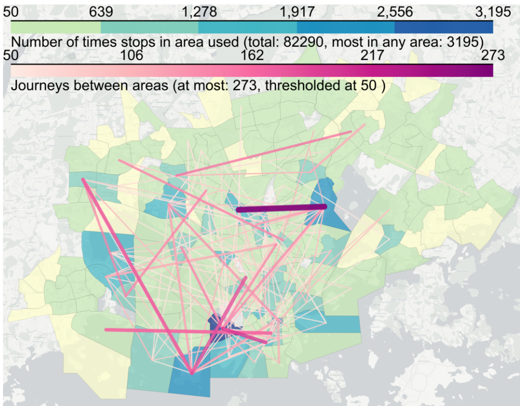
We consider how Kutsuplus journeys were made spatially in the service area, when visualizing data on maps we often threshold data to make sense of the most prominent patterns. All journeys in the data set are visualized in Figure 5.7. Based on Figure 5.7, there seems to be a strong tendency for cross-traffic journeys and the west side of the service area, when compared to the HELMET demand model (See Section 3.3).



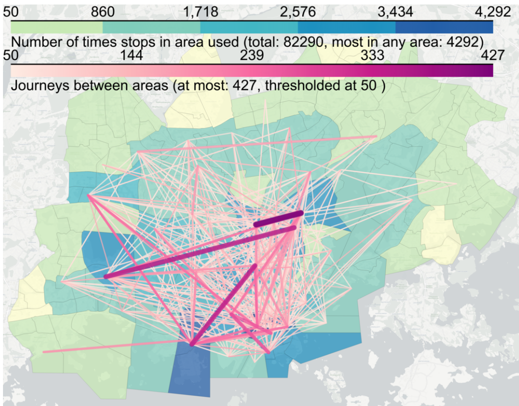
(a) Spatially smoothed (origin)



(b) Spatially smoothed (destination)



(c) Journey destinations on placement zone polygons (SIJ), thresholded at 50 journeys



(d) Journey destinations on prediction zone polygons (ENN), thresholded at 50 journeys

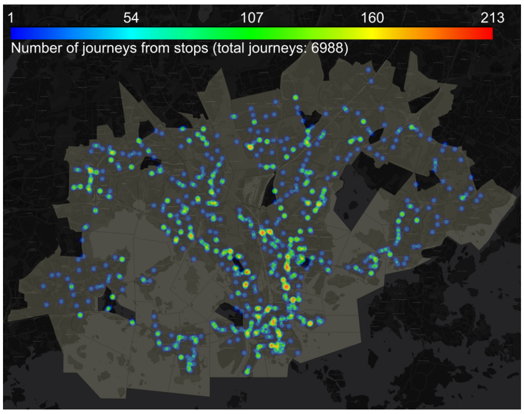
Figure 5.7: Spatial demand for all Kutsuplus journeys. Yellow polygons did not feature demand above the threshold used. Background map: © OpenStreetMap contributors, © CartoDB.

To understand spatial demand better, we have visualized spatial journey demand for the recently defined Kutsuplus MPH (08:00–08:59) and EPH (16:42–17:41) in Figures 5.8 and 5.9. DH demand has been visualized in Figure 5.10 using journeys started between 09:00–14:59 and dividing them by six. We consider only the third and fourth service intervals as these include the whole MR.

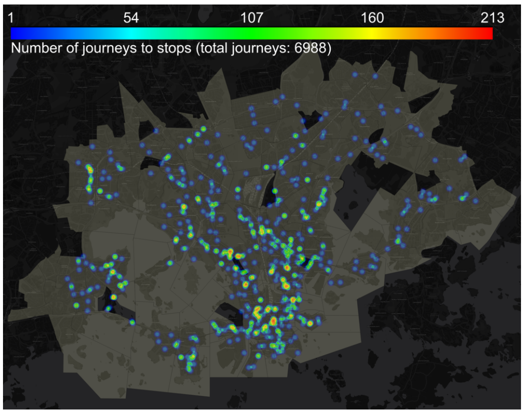
There seems to be a cross-traffic trend for journeys during the MPH. In addition, many journeys end near the city center and areas with significant work and study possibilities, like the Otaniemi university campus and the Pitäjänmäki business area. Whereas practically no journeys were made to the suburban areas of eastern and northern Helsinki and the western edge of the Kutsuplus service area in Espoo.

During the EPH, a similar cross-traffic trend is visible. The city center is also a popular destination. Still, residential areas like Lauttasaari and Ullanlinna are also highlighted. A larger portion of suburban areas is highlighted during the EPH than during the MPH.

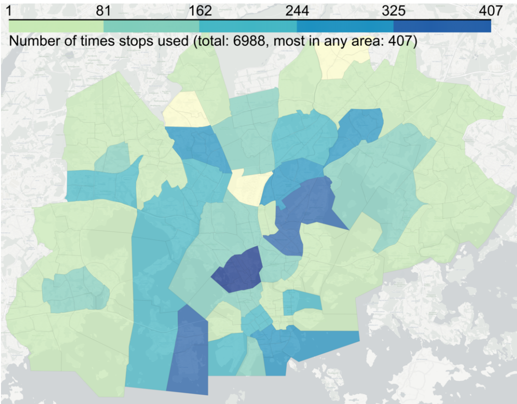
DH demand seems more even with some areas having largely symmetrical demand. Areas like Arabia, Lauttasaari and Otaniemi are both popular origins and destinations, whereas the city center is mainly a popular destination. There seems to be an especially frequent link between Pasila and Arabia. Pasila and the city center provide access to railway stations, which might contribute to their popularity. Pasila and Arabia feature multiple colleges and businesses, so mid-day commuting also seems like a plausible explanation for high demand.



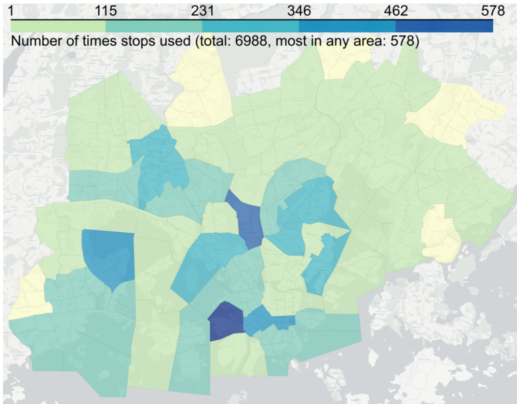
(a) Spatially smoothed (origin)



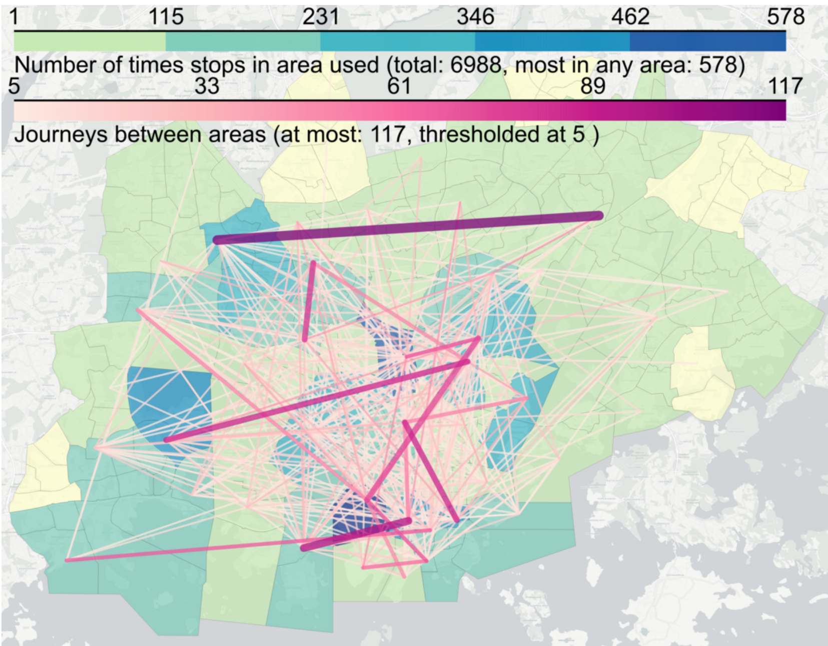
(b) Spatially smoothed (destination)



(c) ENN polygons (origin)

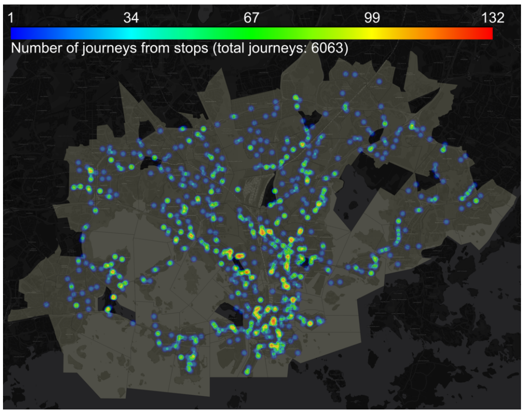


(d) ENN polygons (destination)

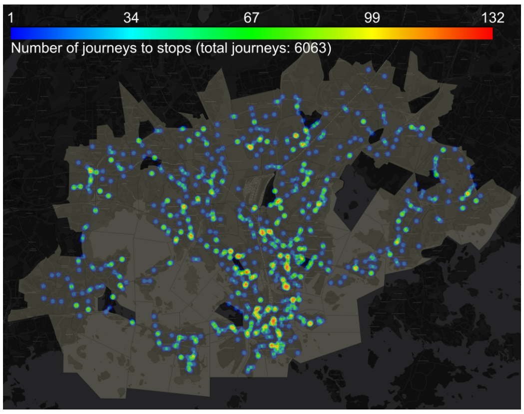


(e) ENN polygons (destination), thresholded at 5 journeys

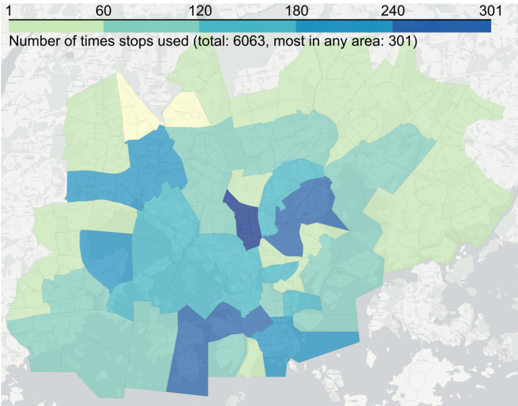
Figure 5.8: MPH (journeys started 08:00-08:59) demand during Kutsuplus service phases 3 & 4. Using prediction zone (ENN) polygons. Yellow polygons did not feature demand above the threshold used. Background map: © OpenStreetMap contributors, © CartoDB.



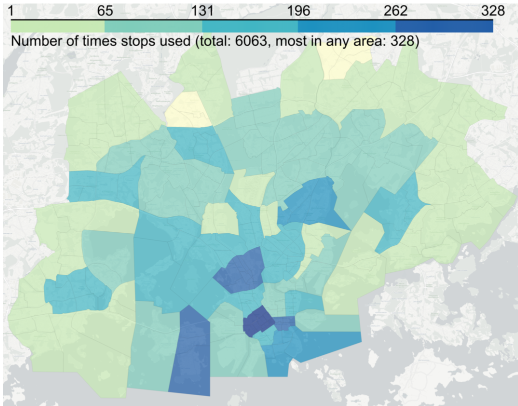
(a) Spatially smoothed (origin)



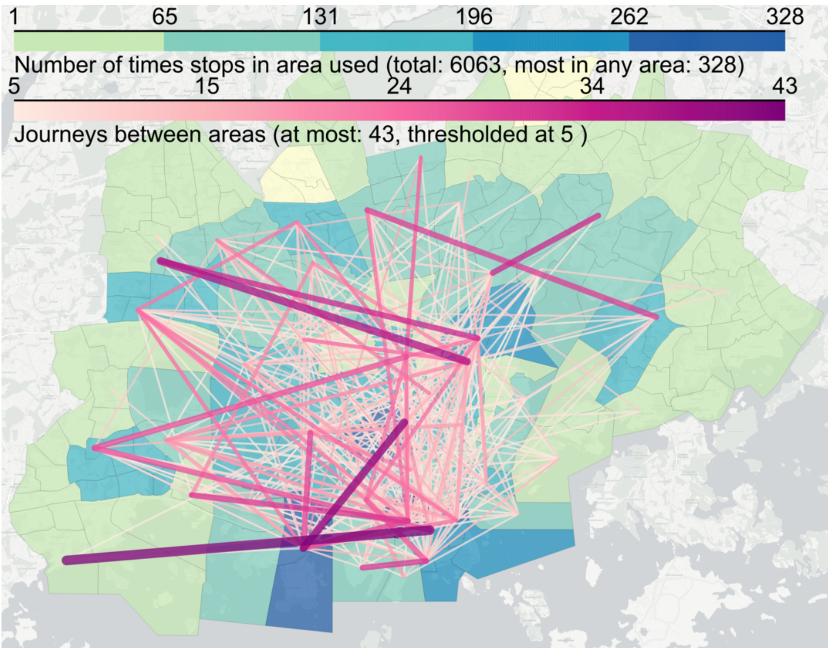
(b) Spatially smoothed (destination)



(c) ENN polygons (origin)

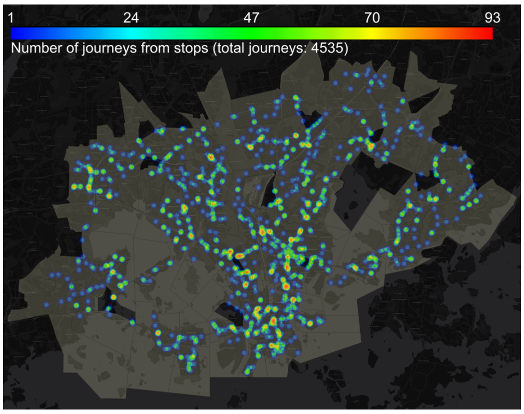


(d) ENN polygons (destination)

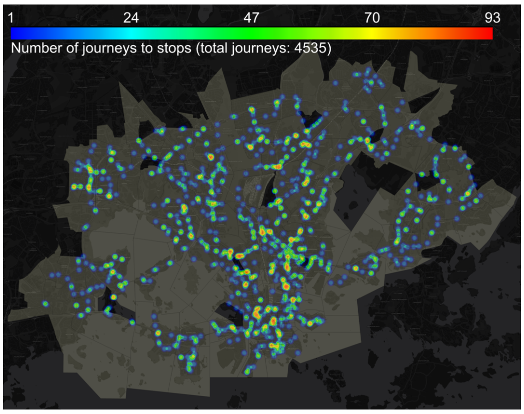


(e) ENN polygons (destination), thresholded at 5

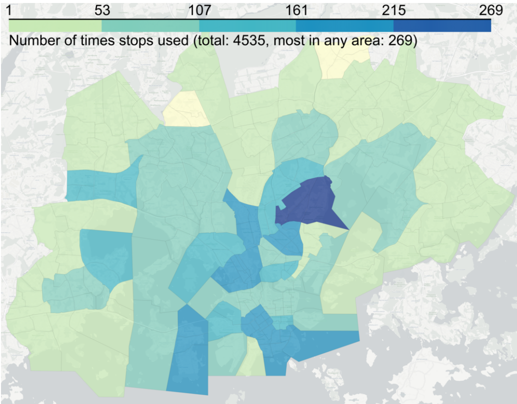
Figure 5.9: EPH (journeys started 16:42-17:41) demand during Kutsuplus service phases 3 & 4. Using prediction zone (ENN) polygons. Yellow polygons did not feature demand above the threshold used. Background map: © OpenStreetMap contributors, © CartoDB.



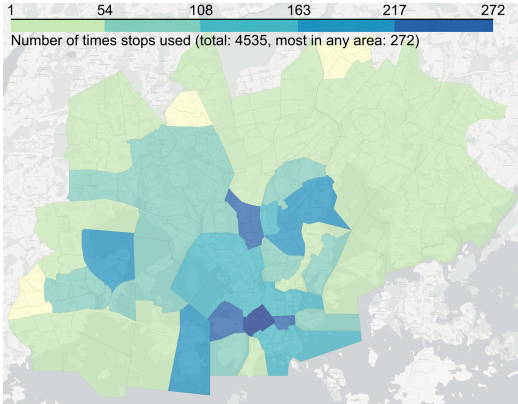
(a) Spatially smoothed (origin)



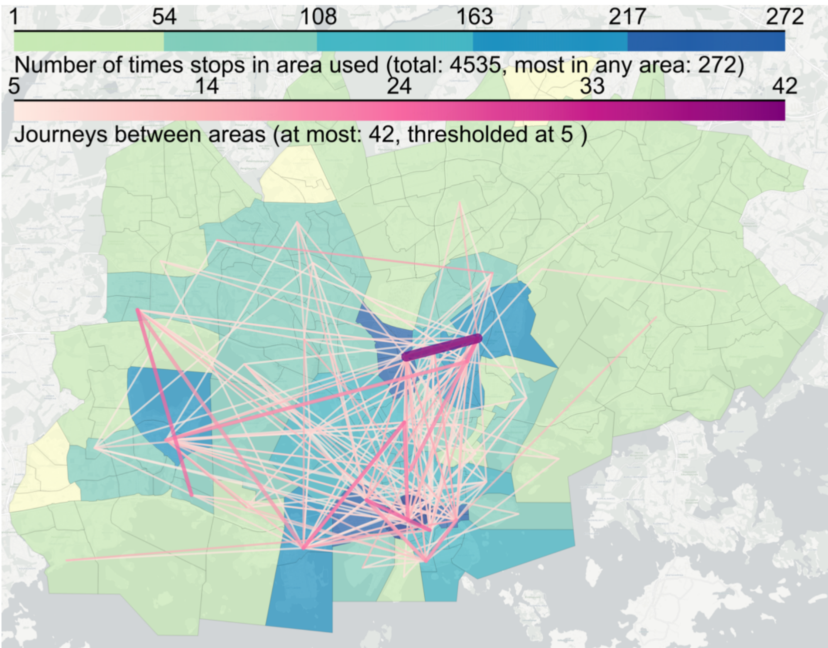
(b) Spatially smoothed (destination)



(c) ENN polygons (origin)



(d) ENN polygons (destination)



(e) ENN polygons (destination), thresholded at 5 journeys

Figure 5.10: DH (one sixth of DT journeys, started 09:00-14:59) demand during Kutsuplus service phases 3 & 4. Using prediction zone (ENN) polygons. Yellow polygons did not feature demand above the threshold used. Background map: © OpenStreetMap contributors, © CartoDB.

5.1.4 Week level patterns

The average number of daily Kutsuplus journeys for each day of the week is shown in Figure 5.11. There seems to be an increase in journeys as the week advances, but the average amount of journeys is relatively stable.

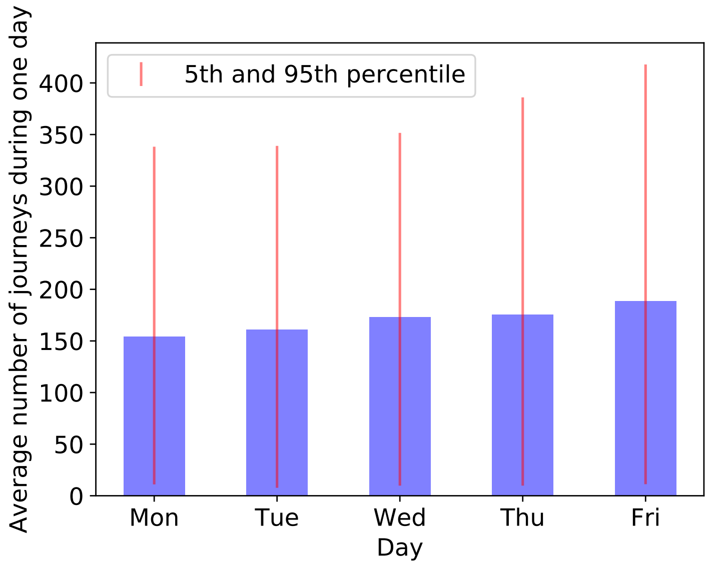
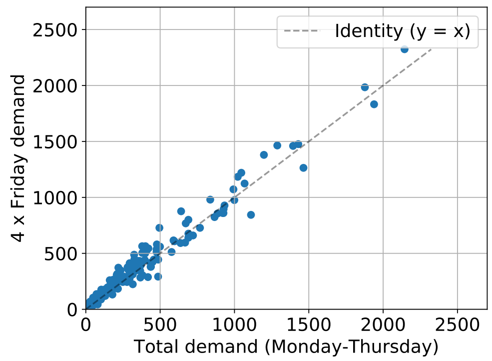


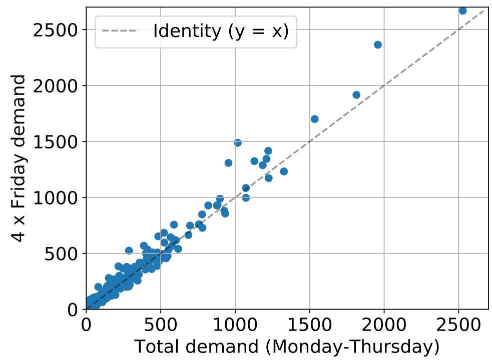
Figure 5.11: Average number of daily journeys for each day of the week (all journeys)

As PT usage may significantly differ between weekdays (Monday to Thursday) and Fridays, we consider potential spatial demand variations for Kutsuplus journeys through the 212 HELMET placement zone (SIJ) polygons that were used for Kutsuplus journeys per the journey data. We use placement zones rather than stops to consider stops that are spatially close to each other together.

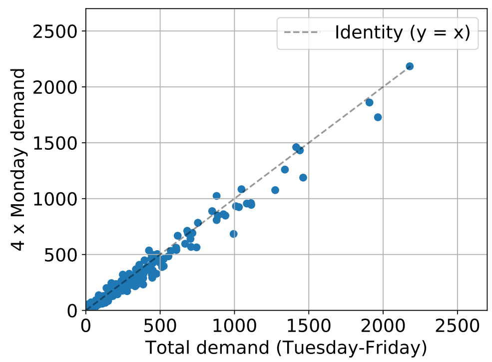
Weekday demand is visualized against demand on Fridays in Figure 5.12. To gain comparable amounts, the demand for Friday is multiplied by 4. As a reference, the demand between Monday and Tuesday to Friday, is also inspected in the same manner. As all scatter plots (Figures 5.12a – 5.12d) largely align on the identity axis, it seems demand was not different between Fridays and weekdays, even though journey amounts appear to increase towards the end of the week. Looking at the heat maps (Figure 5.12e – 5.12f) for demand between polygons the same trend is apparent.



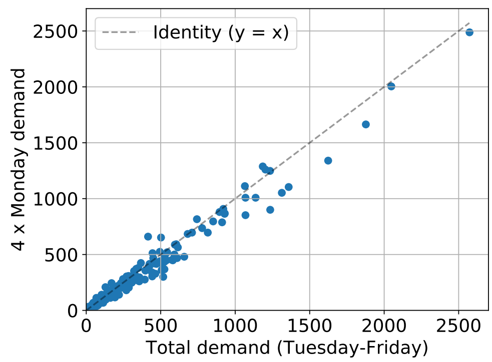
(a) Demand on weekdays vs Fridays (origin)



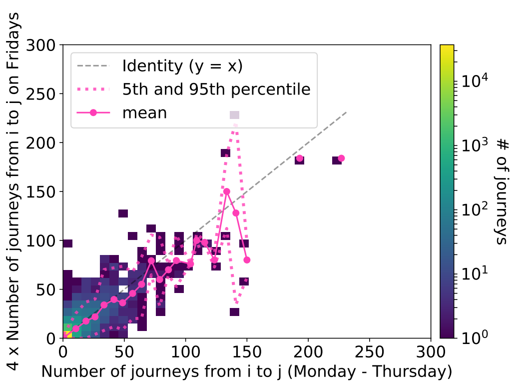
(b) Demand on weekdays vs Fridays (destination)



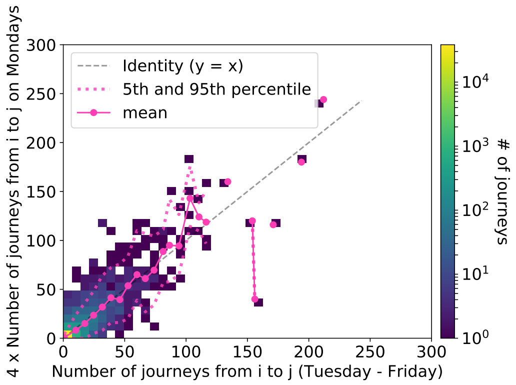
(c) Demand on Tuesday-Fridays vs Mondays (origin)



(d) Tuesday-Fridays vs Mondays (destination)



(e) Demand on weekdays vs Fridays for all SIJ polygon pairs ($i \to j$)



(f) Demand on Tuesday-Fridays vs Mondays for all SIJ polygon pairs ($i \to j$)

Figure 5.12: Demand of placement zone (SIJ) polygons on weekdays vs Fridays and Mondays vs Tuesday–Friday (all journeys).

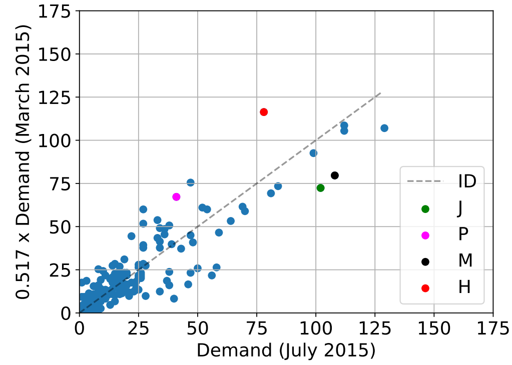
5.1.5 Seasonal differences in demand

We analyze seasonal differences in demand by considering demand between placement zone (SIJ) polygons. We use corresponding methods as those used for distinguishing week level patterns in Section 5.1.4.

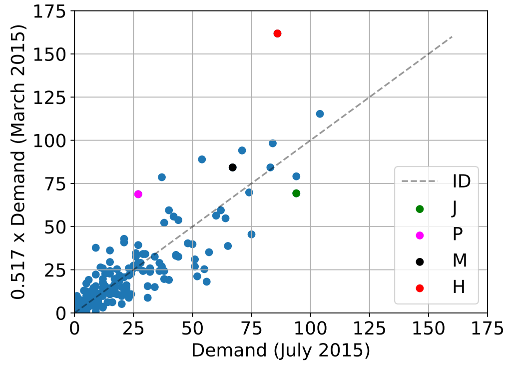
We attempted to consider full seasons separately, but changes in the pilot and months unavailable in the data set made results hard to quantify. To limit complexity, we focus only on the year 2015, investigating demand differences between the typical working month March and the vacation month of July. To further avoid potential effects caused by service area changes, we also considered changes between July and another typical working month, October.

Results are visualized in Figure 5.13. After investigating the demand of all scatters separately, we decide to highlight some of the most distinct demand differences between July and the working months in Figures 5.13a – 5.13d. Demand was higher for the placement zone areas of Pasila and Hermanninmäki during working months. On the other hand, demand for Jätkäsaari and Munkkivuori as origins was lower during the working months. Looking at the heat maps (Figure 5.13e – 5.13f) for demand between polygons, we see that demand does not seem to vary on average, even though some connections are not as prominent, potentially reflecting vacations of regular users.

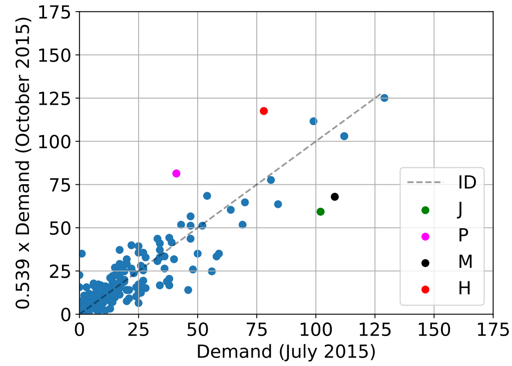
We observed no consistent seasonal demand changes between placement zone areas, which could not be explained by a few regular users. We also computed season specific distributions for the number of passengers, journey distance, journey duration, and age groups. Still, as we found no notable differences when compared to distributions for all journeys, these figures are not shown.



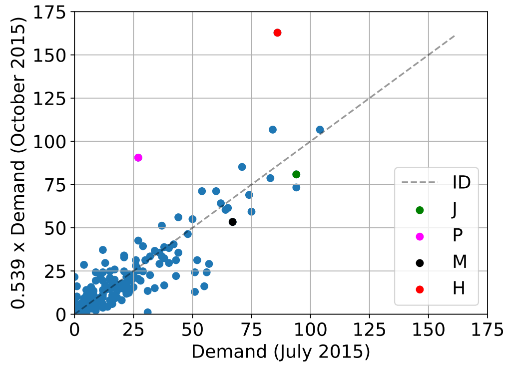
(a) July vs March (origin)



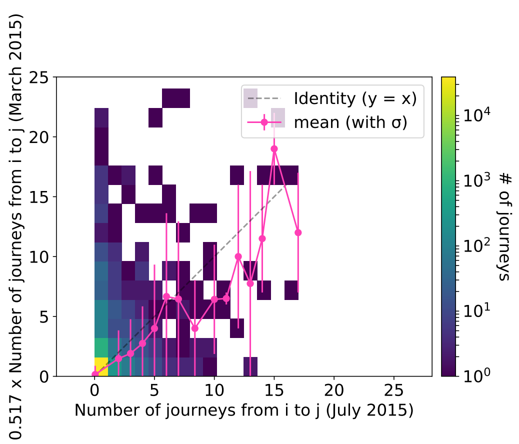
(b) July vs March (destination)



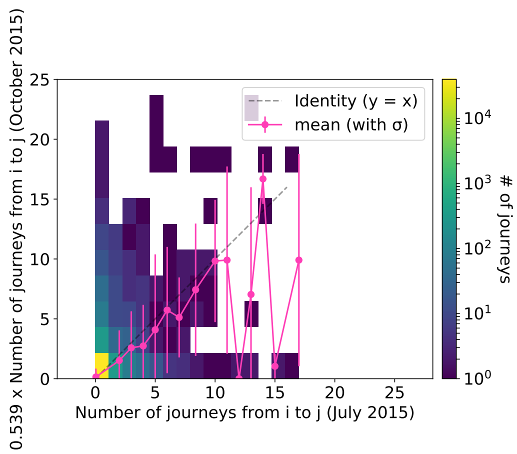
(c) July vs October (origin)



(d) July vs October (destination)



(e) Demand on July vs March for all SIJ polygon pairs ($i \rightarrow j$)



(f) Demand on July vs October for all SIJ polygon pairs ($i \rightarrow j$)

Figure 5.13: Demand of placement zone (SIJ) polygons for July vs March and October (2015). Demand for March and October has been scaled by the number of journeys in July so an equal amount of total demand is considered. In the scatters: ID = Identity , J = Jätkäsaari, P = Pasila, M = Munkkivuori, H = Hermanninmäki

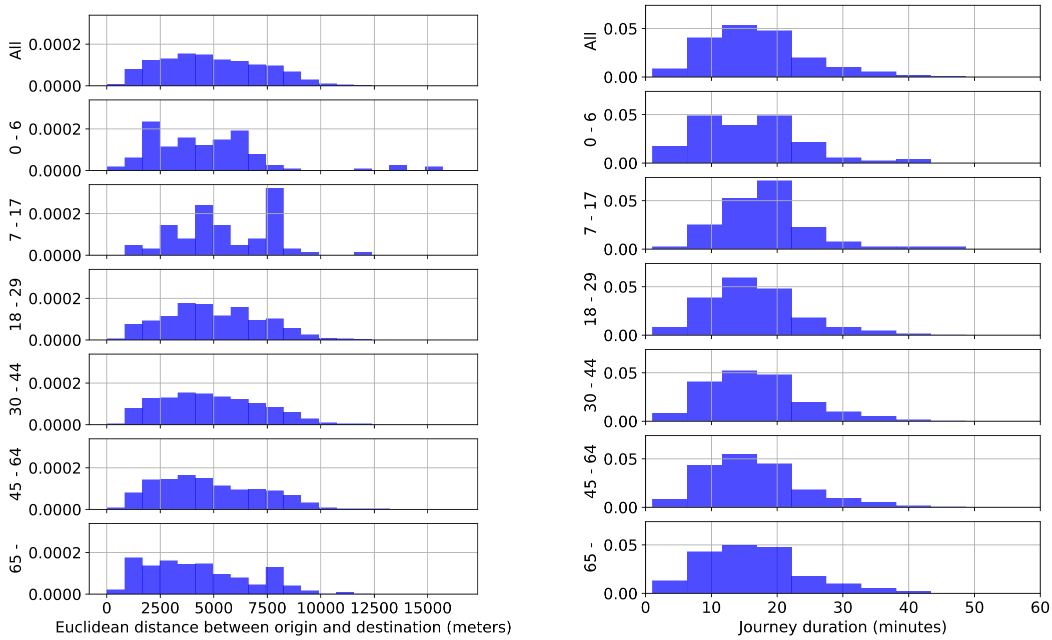
5.1.6 Age groups

We inspect variation between age groups by comparing distributions for journey characteristics for each age group. Information about the number of journeys made by each age group is shown in Table 5.3.

Table 5.3: Number of Kutsuplus journeys by age group

Age group	Journeys
N/A	10298 (12.5%)
0–6	139 (0.2%)
7–17	75 (0.1%)
18–29	9734 (11.8%)
30–44	41044 (49.9%)
45–64	19001 (23.1%)
over 65	1999 (2.4%)
All	82290 (100%)

Distributions for journey distance and duration, in which age groups have been considered separately, are visualized in Figure 5.14. There do not seem to be any notable deviations when we account for the low number of journeys of the age groups '0–6', '7–17', and 'over 65'.



(a) Journey distance (b) Journey duration

Figure 5.14: Probability density distributions for Kutsuplus journeys by age group (all journeys)

To inspect if the peak structure for age groups is different from the peak structure for general trips we considered the fourth service phase separately as the most active Kutsuplus phase. We present the number of journeys made by different age groups during the fourth service phase in Figure 5.15.

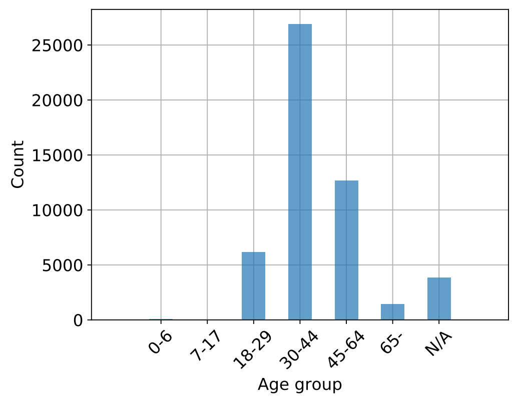


Figure 5.15: Number of Kutsuplus journeys by age group (Fourth service phase)

The daily number of journeys by age group as a function of time has been visualized in Figure 5.16 for the most common age groups. There do not seem to be any notable deviations from the general peak structure. For uncommon age groups, where there was not sufficient data to pinpoint trends, we include the Appendix Figure B.2.

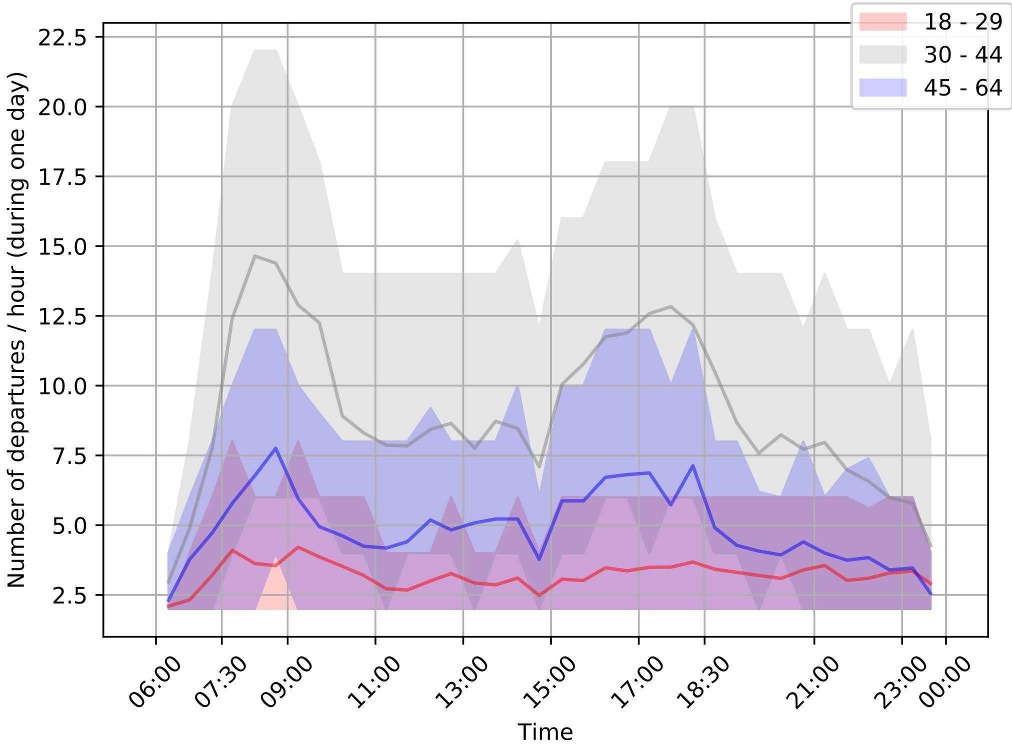
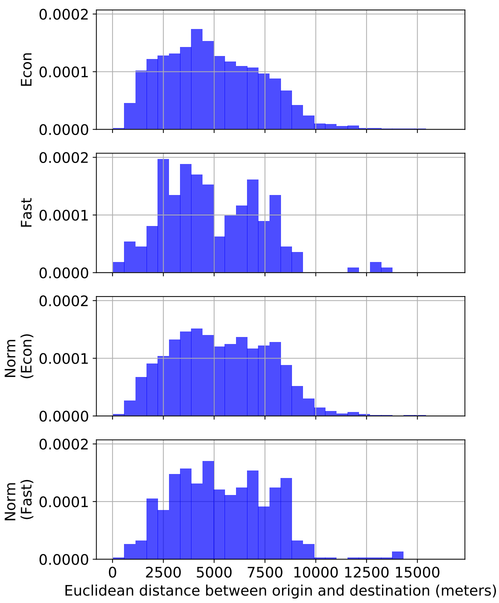


Figure 5.16: Kutsuplus journey amounts for the most common age groups (Fourth service phase). 10th and 90th percentile limited area as background

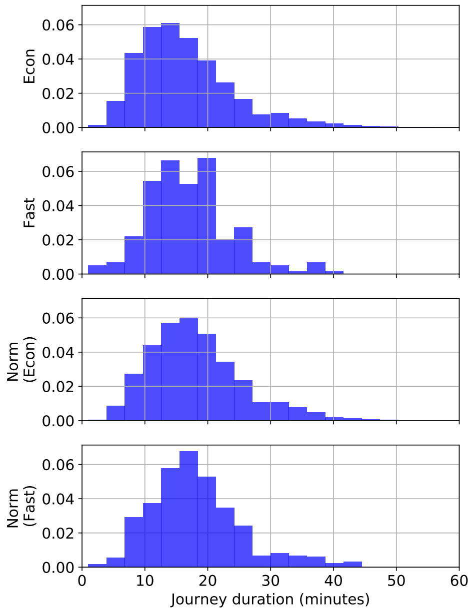
5.1.7 Service classes

As Kutsuplus was one of the rare PT services that enabled paying for a higher LoS, we will analyze Kutsuplus Fast and Economy separately. The campus pilot phase is mostly ignored due to very different pricing. The pilot for Kutsuplus Fast was 11.3.2013–2.4.2013 (excluding pilot 3.4.2013–17.11.2013) and for Economy 8.2.2013–2.4.2013 (excluding pilot 3.4.2013–11.1.2015), so in practice we inspect Fast usage from 4/2013 to 11/2013 and Economy usage from 12/2013 to 4/2015 to clearly differentiate between the service classes. The service classes were effectively only active when service usage was relatively low. Especially the Fast service operated for less than one year, and is represented by only five months in the data set, three of which are summer months.

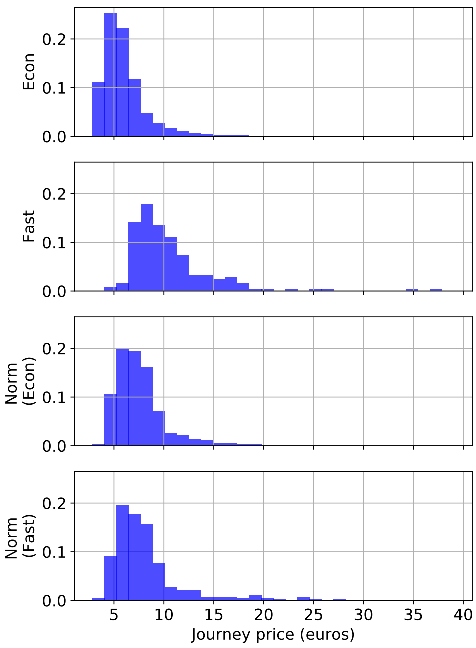
Service class specific distributions for journey distance, duration, price and travel speed are visualized in Figure 5.17. While kutsuplus Fast journeys were more expensive (Figure 5.17c) they do not seem to have been different in terms of distance or duration to normal journeys (Figures 5.17a and 5.17a). We compute an approximation for journey speed in Figure 5.17d, which implies that neither Kutsuplus Fast nor Economy journeys were more or less efficient than the default service class provided.



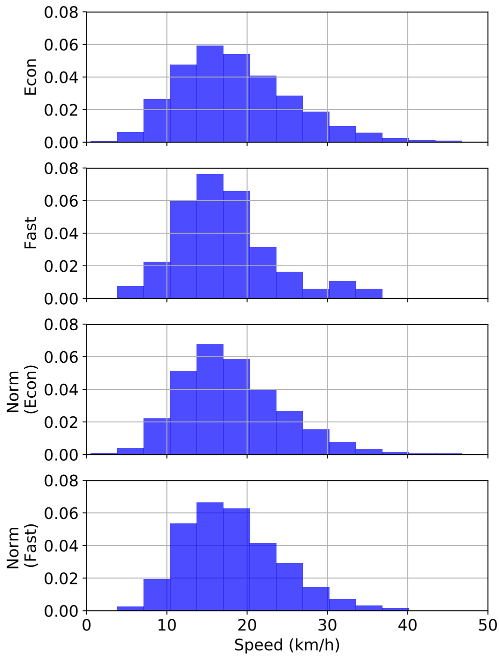
(a) Journey distance



(b) Journey durations



(c) Journey price



(d) Journey speed, using Euclidean distance per realized journey duration

Figure 5.17: Probability density distributions for Kutsuplus journeys by service class. Fast and Normal during (3.4-7.11/2013), Economy and Normal during economy (18.11.-11.1.2015).

We further inspect whether temporal demand peaks for the service classes are similar to the general Kutsuplus service, visualized in Figure 5.18. We note no differences to the general peak structure. We also inspected the daily time dimension for journey passenger amounts, wait times, distance, price, and duration, but found no notable differences to the general trend during the corresponding service intervals, hence these are not shown.

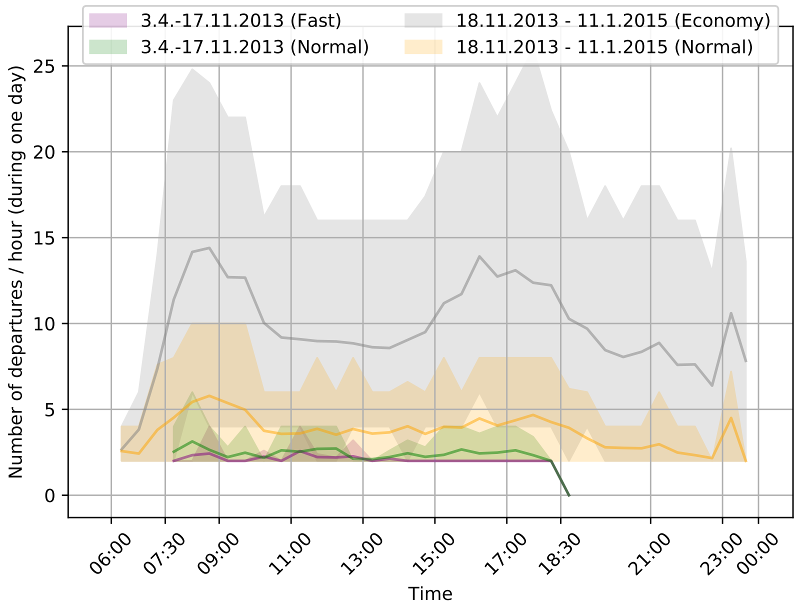
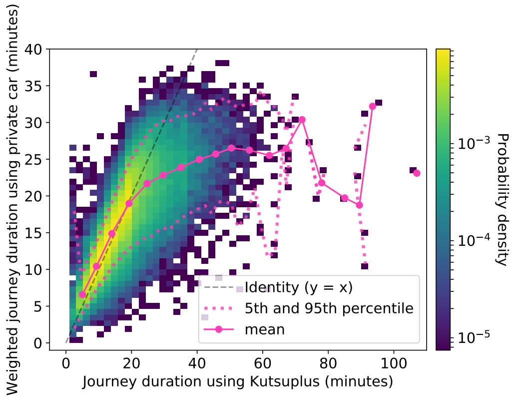


Figure 5.18: Journey amounts for different service classes. 10th and 90th percentile limited area as background.

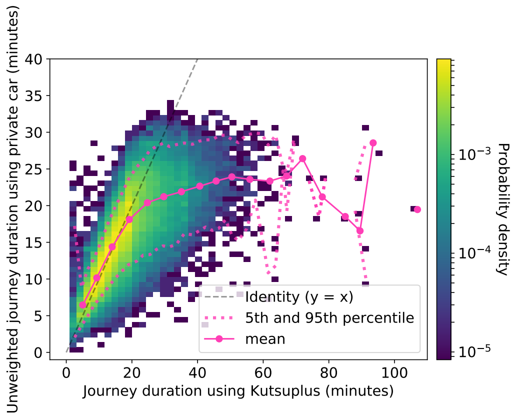
5.2 Comparing journey alternatives

5.2.1 Journey duration

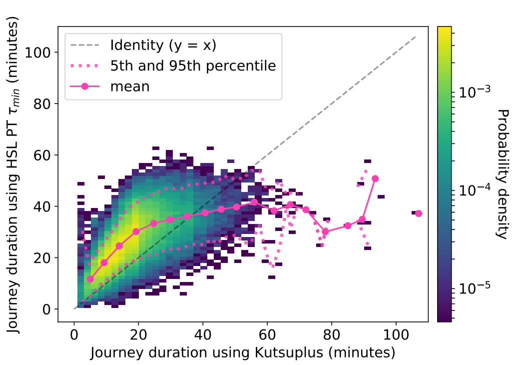
Journey durations of travel mode alternatives are compared to Kutsuplus in Figure 5.19. Kutsuplus journey duration was comparable to car usage when journeys lasted up to 20 minutes, after which car journeys were generally faster (Figures 5.19a and 5.19b). PT was slower than Kutsuplus (Figures 5.19c and 5.19d), but this does not account for time spent ordering and waiting. Walking was much slower than Kutsuplus (Figure 5.19e), while cycling could have been used as a faster travel option for almost a fifth of all Kutsuplus journeys (Figure 5.19f).



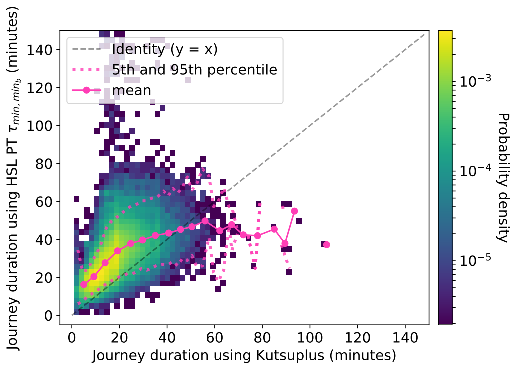
(a) Kutsuplus vs car/Uber (traffic weighted), car is faster 46.0% of the time



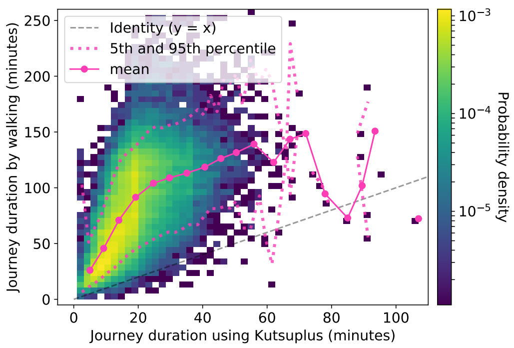
(b) Kutsuplus vs car/taxi (traffic unweighted), car is faster 53.5% of the time



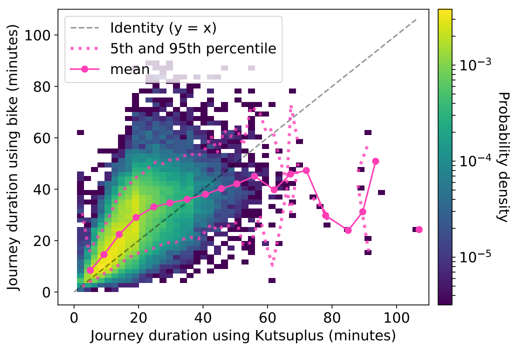
(c) Kutsuplus vs PT τ_{min}, PT is faster 7.8% of the time



(d) Kutsuplus vs PT τ_{min,min_b}, PT is faster 5.4% of the time)



(e) Kutsuplus vs walking, walking is faster 0.2% of the time



(f) Kutsuplus vs cycling, cycling is faster 18.6% of the time

Figure 5.19: Journey durations of all Kutsuplus journeys against alternative modes of travel (PT using a 2 km walking cutoff)

Journey durations of Kutsuplus against PT with 0.5km walk legs are shown in Appendix Figure B.3. We also show how journey duration increases as a function of journey distance for private car, biking and walking in Appendix Figures B.5, B.6 and B.7 respectively.

5.2.2 Journey price

Jouney price as a function of time of day is visualized in Figure 5.20. Uber BLACK is dropped from the Figure to keep the range narrower. BLACK was approximately 10 € more expensive than taxis during daytime, around 7e in the evenings. Taxi use an increased pricing model during evenings, which accounts for the evening peak. Pricing for all modes except for PT correlate with journey distance and there are no other significant variations by the time of day. Because municipality borders are the only cause of pricing differences for PT we consider regional fare zones separately in Section 5.3.1.

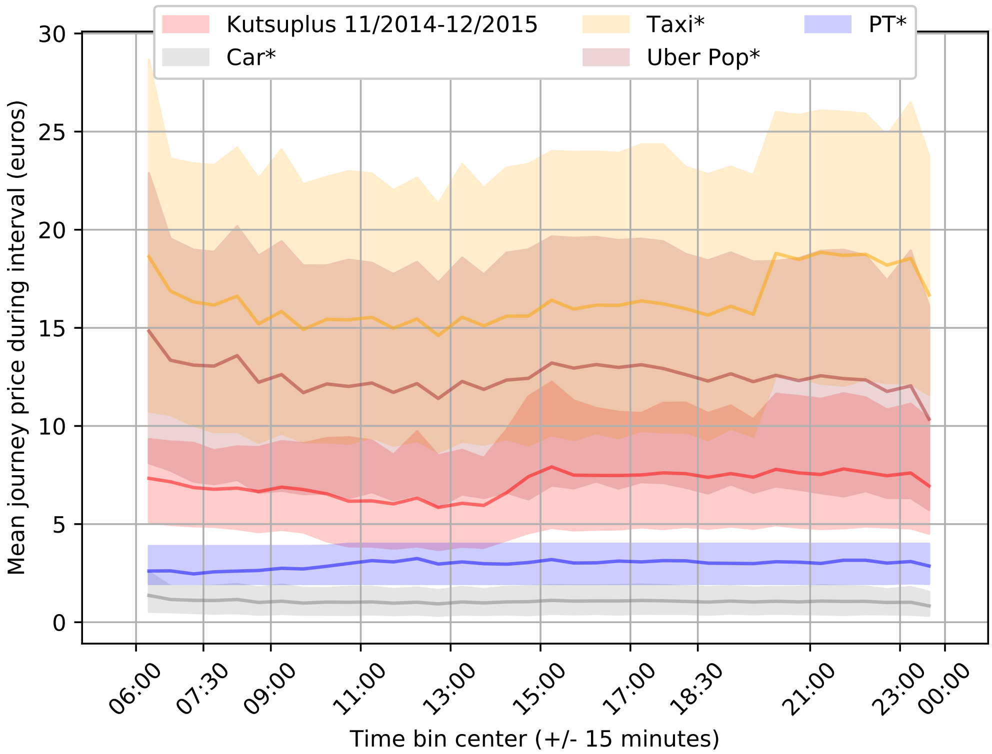


Figure 5.20: Mean journey prices for Kutsuplus and alternative travel modes. 10th and 90th percentile limited area as background.

5.3 Public transport specific features

5.3.1 Fare zones

We consider the portion of journeys made by Kutsuplus users between different PT fare zones, because it might be tempting for PT users to use Kutsuplus over regional borders as regional PT tickets are more expensive than single-region tickets. The distribution of journey regionality for different age groups is shown in Figure 5.21. As the sample size for age groups 0–6 and 7–17 is very low, we do not consider them in detail (see Table 5.3). It would seem like 18–29-year-olds used Kutsuplus more for regional journeys relatively often. On the other hand, over 65-year-olds used Kutsuplus mainly for journeys inside Helsinki.

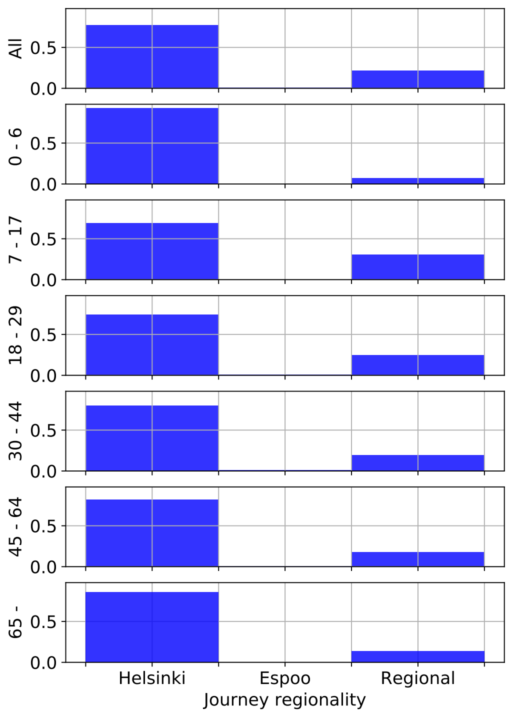
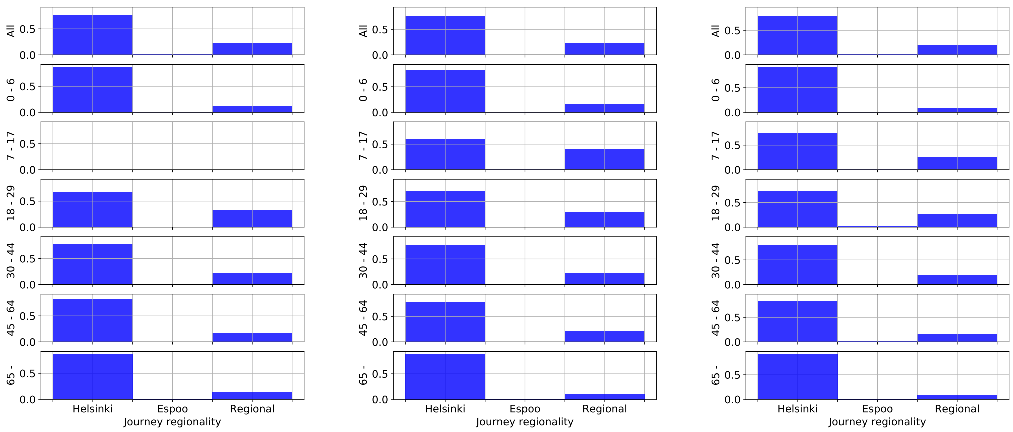


Figure 5.21: Probability density distributions for Kutsuplus journey PT fare zone usage by age group (All journeys)

We also considered fare zones separately for MPH, EPH and DH during the third and fourth service phases. Regionality during MPH is visualized in Figure 5.22a. During MPH, it is more prominent that 18–29 olds used Kutsuplus for regional journeys relatively often. For MPH, EPH (Figure B.8a), and DH (Figure B.8b), over 65-year-olds used Kutsuplus almost exclusively for journeys inside Helsinki.



(a) KP MPH (08:00–08:59)

(b) KP EPH (16:42–17:41)

(c) KP DT (09:00–14:59)

Figure 5.22: Probability density distributions for Kutsuplus journey PT fare zone usage by age group (third and fourth service phase)

The temporal demand peak structure of journeys by different PT fare zone during the fourth interval is shown in Figure 5.23. We find that journeys do not differ from the general peak structure (as shown in Figure 5.4). More detailed journey fare zone portions for Kutsuplus service classes are shown in Appendix Table B.1.

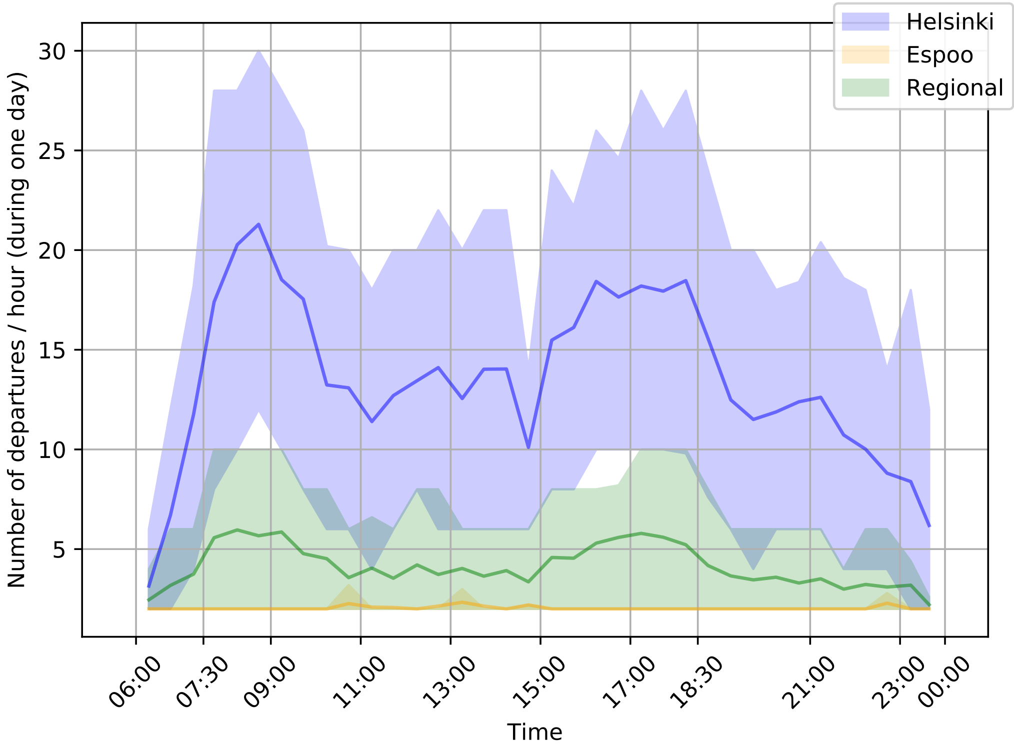


Figure 5.23: Number of journeys by PT fare zone (Fourth interval). 10th and 90th percentile limited area as background

5.3.2 Amount of walking

PT computations have been done in a manner that allows a walk between two stops if they are at most 2 km apart, but not chaining multiple walks after one another. We quantify the effects of different walking limits in Table 5.4 through impractical journeys. Journeys are considered impractical when PT routing defines journey alternatives as unavailable within the travel window. Walking was not a feasible option for replacing Kutsuplus travel, but when limiting walk distances to 2 km every twentieth Kutsuplus journey could have been completed by walking. Though, only 0.06 % (less than 50 journeys) would have been faster by walking than using a PT vehicle.

Table 5.4: Walking as an PT option for all Kutsuplus journeys

Limit (km)	Walking a PT option (%)	Walking fastest PT option (%)	Impractical journeys (%)
0.5	0.04	0.02	1.22
1.0	0.58	0.05	0.01
1.5	2.53	0.06	≈ 0
2.0	4.80	0.06	0

We show the number of impractical journeys for different age groups in Table 5.5. In Table 5.6 we further look specifically at the 0.5km limit, which causes the highest amount of impractical journeys, together with information about age group journey portions. Based on Table 5.6 it appears Kutsuplus was not used by specific age groups for PT routes which required considerable amounts of walking.

Table 5.5: Impractical walking by age groups for all Kutsuplus journeys

Limit (km)	0 – 6	7 – 17	18 – 29	30 – 44	45 – 64	65–	N/A	Total
0.5	0	1	77	547	240	74	63	1001
1.0	0	0	4	7	0	0	0	11
1.5	0	0	1	0	0	0	0	1
2.0	0	0	0	0	0	0	0	0

Table 5.6: Portion of journeys and portion of impractical PT journey alternatives by age group. All Kutsuplus journeys with a 0.5km walking leg limit.

Ages group	0 – 6	7 – 17	18 – 29	30 – 44	45 – 64	65–	N/A
Journeys	0.2%	0.1%	11.8%	49.9%	23.1%	2.4%	12.5%
Impractical	0.0%	0.1%	7.70%	54.6%	24.0%	7.4%	6.3%

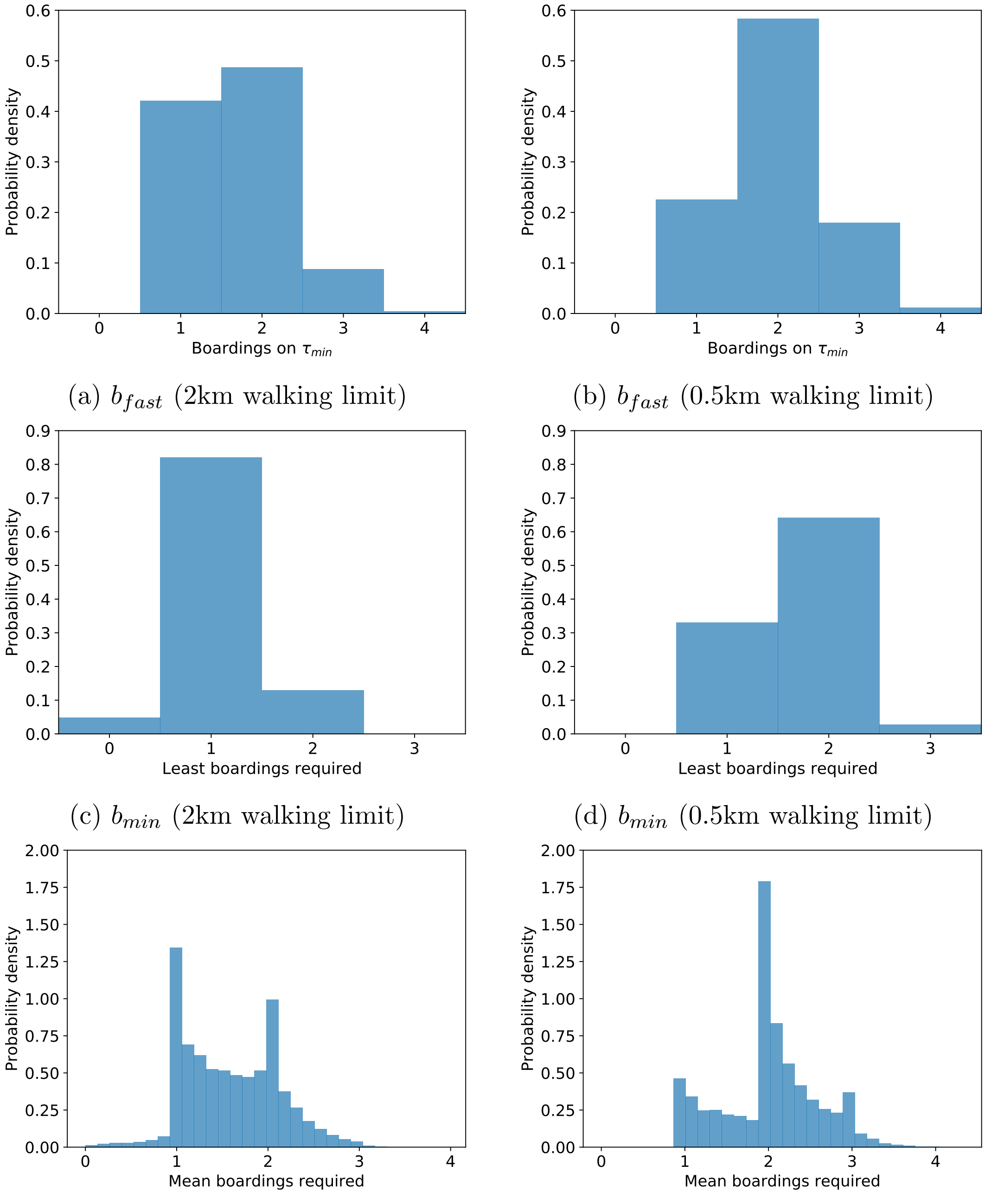
5.3.3 Number of boardings

If departure is planned, users may select the best journey alternative by some criterion. We consider the best alternative to either have the smallest temporal distance or the least number of boardings. We visualize distributions of these for both 2km and 0.5km limits on walking legs in Figure 5.24.

Looking at boarding number for the smallest temporal distance, a large portion of journeys could have been made with either one or two boardings, if a 2km limit on walking was used (Figure 5.24a). When the cutoff is reduced to 0.5km, most journeys require two boardings and a considerable portion even three (Figure 5.24b).

If we consider the least number of boardings required (Figure 5.24c), a 2km limit enable walking as a mode for some of the journey alternatives, as observed in Section 5.3.2. Still, one vehicle boardings is the most common option, seldom two. On the other hand, a 0.5km limit on walking (Figure 5.24d) quickly increases the required number boardings. While one boarding may suffice, most of the time two are required, sometimes even three.

The same trend we observed for the least number of boardings is visible for the mean number of boardings required on fastest-path journey alternatives (Figures 5.24e and 5.24f). Though boarding numbers are higher, this is to be expected, as not only the shortest temporal distance is considered.



(a) b_{fast} (2km walking limit)

(b) b_{fast} (0.5km walking limit)

(c) b_{min} (2km walking limit)

(d) b_{min} (0.5km walking limit)

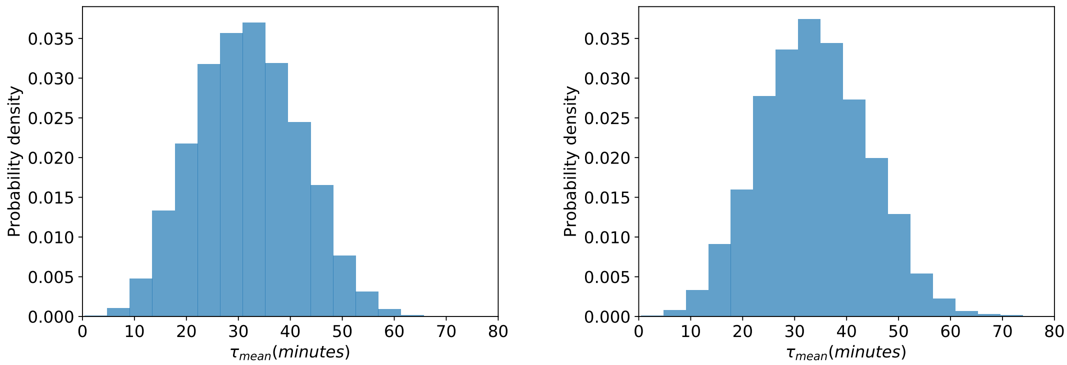
(e) b_{mean} (2km walking limit)

(f) b_{mean} (0.5km walking limit)

Figure 5.24: Boarding distributions for planned PT usage (all journeys)

5.3.4 Spontaneous travel

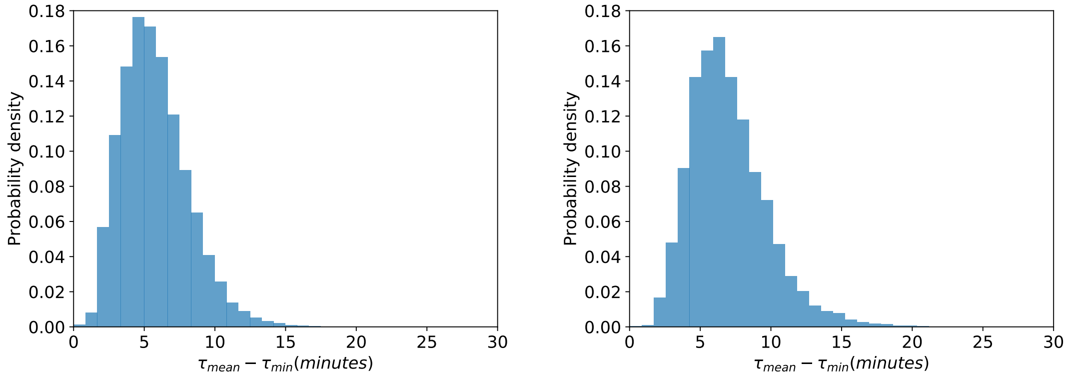
The mean travel time for a spontaneous departure τ_{mean} is visualized in Figures 5.25a and 5.25b. Walking limit reductions cause a slight increase in τ_{mean}. When departing spontaneously, some time may be lost waiting for a τ_{min} connection. We visualize the time lost $\tau_{mean} - \tau_{min}$ for 2km and 0.5km walking limits in Figures 5.26a and 5.26b. Using a 2km limit, PT users would have to wait a few minutes less for the optimal journey option, than when using a 0.5km limit for walking.



(a) τ_{mean} (2km walking limit)

(b) τ_{mean}, (0.5km walking limit)

Figure 5.25: Journey duration for spontaneous PT usage

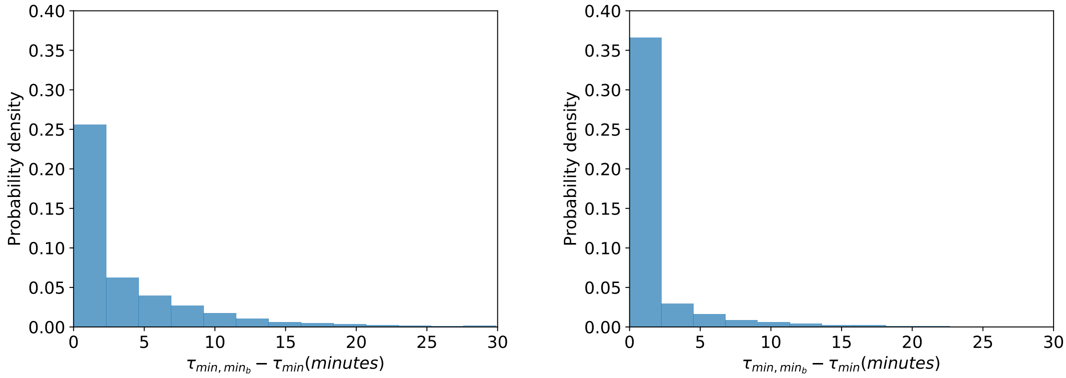


(a) Time lost waiting for τ_{min} (2km walking limit)

(b) Time lost waiting for τ_{min}, (0.5km walking limit)

Figure 5.26: Waiting times for spontaneous PT usage

If a PT user would have wanted to use the fastest-path option featuring the least number of vehicle boardings (τ_{min,min_b}) instead of the shortest temporal distance option τ_{min}, they would have lost a few minutes of time. The time lost was on average slightly longer for a 2km walking limits (Figure 5.27a) than for 0.5km (Figure 5.27b). This is possibly due to a larger number of available PT options in the vicinity, when walking to stops further away becomes possible.



(a) Time lost using τ_{min,min_b} over τ_{min} (2km walking limit)

(b) Time lost using τ_{min,min_b} over τ_{min} (0.5km walk limit)

Figure 5.27: Time lost using option with least vehicle boardings

Boarding counts for different age groups were inspected, but there was no notable difference between them. The same holds true for the different service classes of Kutsuplus. Thus, these are not shown.

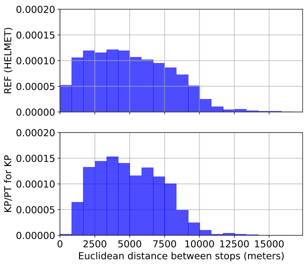
5.4 Reference models

In this section, results for comparing Kutsuplus journeys to reference model journeys will be presented. For the HELMET reference model, we generated specific journeys for MPH, EPH, and DT respectively. For the random (R) and distance sampled (DS) models we only generate one set of journeys each, which we route for MPH, EPH and DH. For R, because time of day does not affect generation. For DS, because differences between MPH, EPH and DT distance distributions are minor (visualized in Appendix Figures B.1 and B.1b). All reference models are considered with a 2km limit for walking legs.

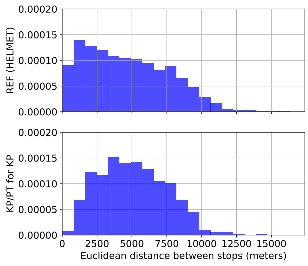
First, we consider basic statistics in form of journey distance, duration, and speed. Second, we consider PT specific features through waiting times, fare zones and the amount of boardings. Finally, we consider demand variations between models and spatial demand.

Journey distance

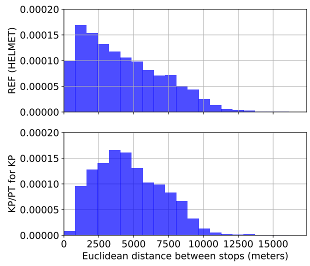
Reference journey distances are visualized in the Figure 5.28. During the MPH (Figure 5.28a) and EPH (Figure 5.28b), the Kutsuplus distance distribution was less spread out than the HELMET reference distribution. The same holds for during DT (Figure 5.28c), but there appears to be multiple short HELMET journeys. DS journey lengths (Figure 5.28d) correspond to Kutsuplus journey lengths, as is expected. R journey lengths (Figure 5.28d) are more spread out and somewhat longer than Kutsuplus journeys, highlighting common distances between stop pairs.



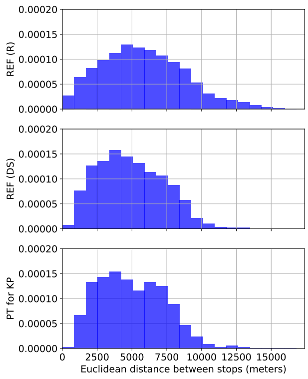
(a) MPH



(b) EPH



(c) DT

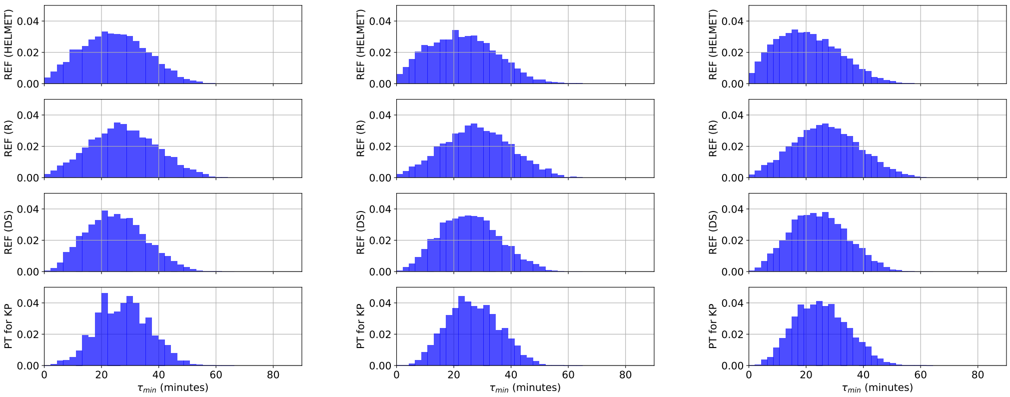


(d) All

Figure 5.28: Probability density distributions for reference journey distances (Euclidean between stops). Kutsuplus journeys for phases 3 and 4.

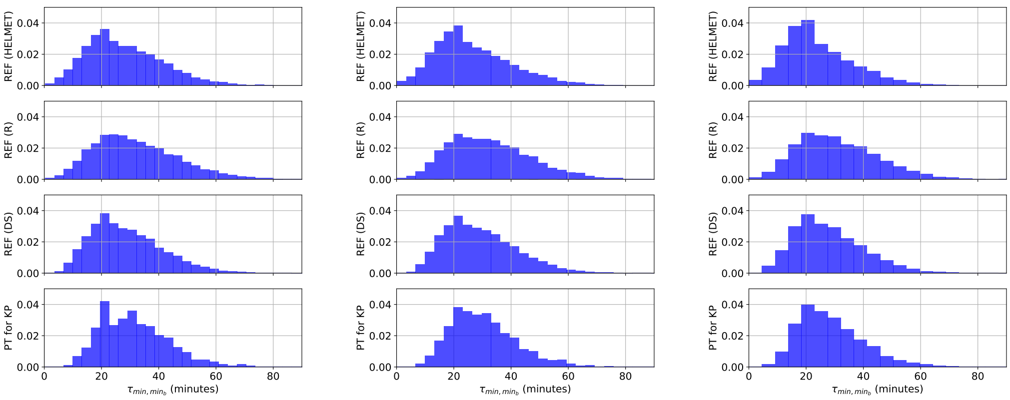
Journey duration

Reference journey durations are visualized for τ_{min} and τ_{min,min_b}. For τ_{min}, in Figures 5.29a, 5.29b and 5.29c, HELMET journeys tend to last slightly shorter than other models, while R journeys last slightly longer. The distributions for other modes are more spread out than the duration distributions of PT alternatives for Kutsuplus. The spreading proportions correspond to those observed for journey distances. The same may be observed for τ_{min,min_b}, in Figures 5.30a, 5.30b and 5.30c.



(a) MPH (b) EPH (c) DT

Figure 5.29: Probability distributions for reference journey durations (τ_{min}). Kutsuplus journeys for phases 3 and 4.



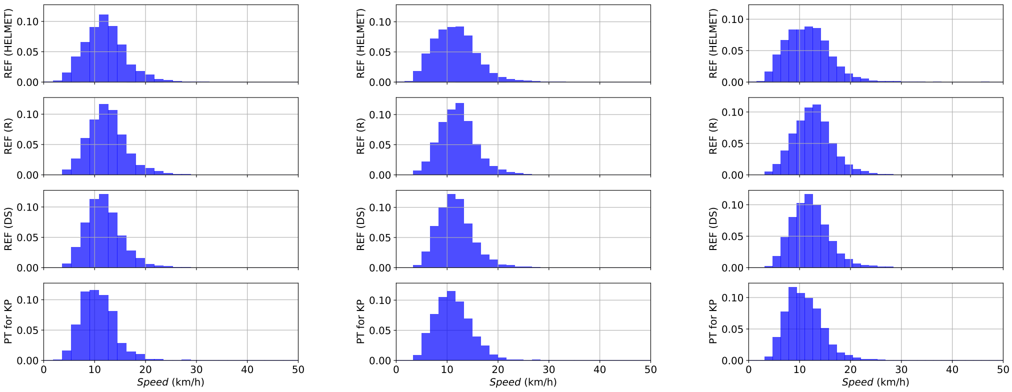
(a) MPH (b) EPH (c) DT

Figure 5.30: Probability density distributions for reference journey durations (τ_{min,min_b}). Kutsuplus journeys for phases 3 and 4.

Journey speed

We compute an approximation for journey speed using the Euclidean distance between stops and τ_{min} and τ_{min,min_b} in Figures 5.31 and 5.32 respectively.

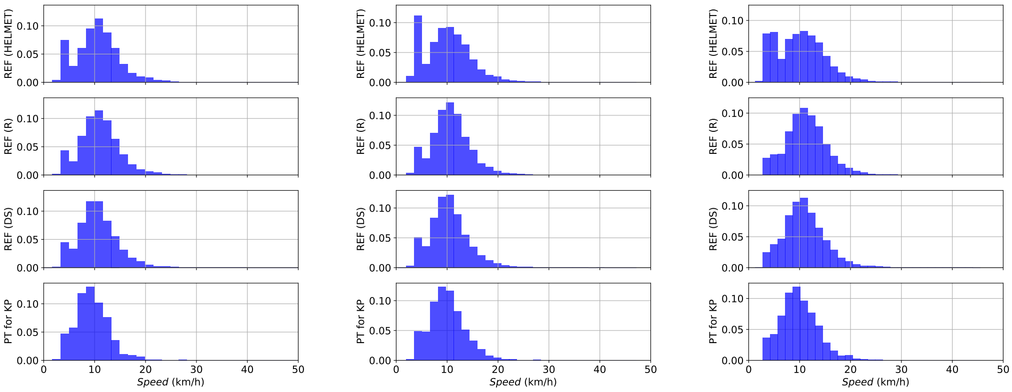
For τ_{min}, we observe that all reference models largely correspond to each other (Figures 5.31a, 5.31b and 5.31c). Though PT for replacing Kutsuplus appears slightly slower MPH, EPH and DH, this is considered minor.



(a) MPH (b) EPH (c) DT

Figure 5.31: Probability density distributions for reference journey speed (km/h) as Euclidean distance per τ_{min}. Kutsuplus journeys for phases 3 and 4.

For τ_{min,min_b}, in Figures 5.32a, 5.32b and 5.32a we notice that especially the HELMET reference journeys feature a sharp peak at around 5 km/h speeds. The peak is around walking speed and likely caused by walking being an option for the short journey distances noted earlier. For τ_{min,min_b}, PT alternatives for Kutsuplus do seem to have marginally less around 20 km/h speed journeys than the references.

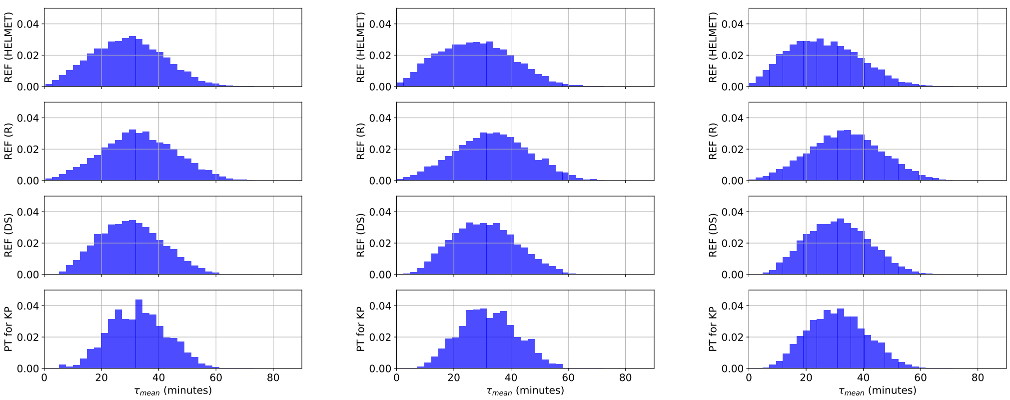


(a) MPH (b) EPH (c) DT

Figure 5.32: Probability density distributions for reference journey speed (km/h) as Euclidean distance per τ_{min,min_b}. Kutsuplus journeys for phases 3 and 4.

Spontaneous travel

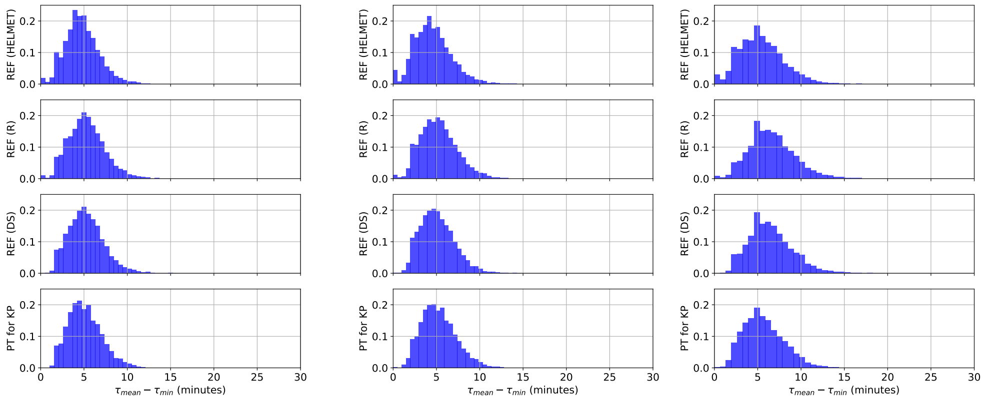
Our measure for spontaneous journey duration, τ_{mean}, is visualized in Figures 5.33a, 5.33b and 5.33c. We see that HELMET journeys tend to last a shorter time than other models, while R and DS journeys roughly correspond to PT alternatives for Kutsuplus. The distributions for HELMET, DS, and R are again more spread out than the duration distributions of PT alternatives for Kutsuplus.



(a) MPH (b) EPH (c) DT

Figure 5.33: Probability density distributions for τ_{mean}.

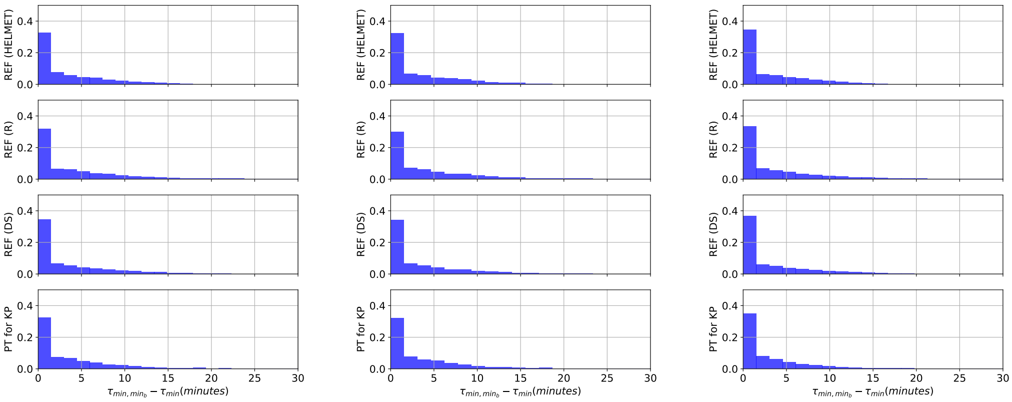
We show $\tau_{mean} - \tau_{min}$ in Figures 5.34a, 5.34b and 5.34c. We notice that HELMET and R feature a small peak around 0, which could be from routes where walking is always the fastest PT option. Otherwise wait time lost seems to be centered around 5 minutes for all distributions, with a slightly longer tail for DT, which is to be expected, as PT operation is not as frequent as during rush hours.



(a) MPH (b) EPH (c) DT

Figure 5.34: Probability density distributions for time lost waiting for τ_{min}. Kutsuplus journeys for phases 3 and 4.

We show $\tau_{min,min_b} - \tau_{min}$ in Figures 5.35a, 5.35 and 5.35c. For MPH, EPH and DT, usually less than 5 minutes is lost when choosing the option with least boardings. We notice that during DT slightly less time is lost, but differences between MPH, EPH, DT for the different reference models are minor.

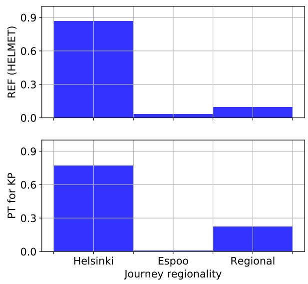


(a) MPH (b) EPH (c) DT

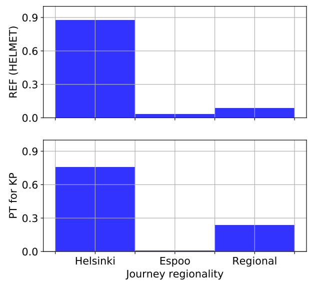
Figure 5.35: Probability density distributions for time lost using τ_{min,min_b} over τ_{min}. Kutsuplus journeys for phases 3 and 4.

Fare zones

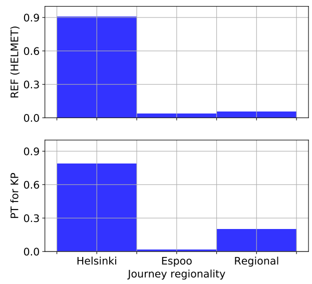
We visualize the usage portions of different PT fare zones in Figures 5.36a, 5.36b, and 5.36c. We notice that Espoo journeys are more common in the HELMET model than for PT alternatives for Kutsuplus. Kutsuplus use was often regional during MPH, EPH and DT, but also on the day level (Figure 5.36d). The portion of regional journeys is larger in DS and R than HELMET.



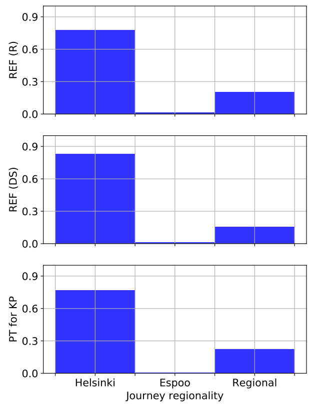
(a) MPH



(b) EPH



(c) DT



(d) All

Figure 5.36: Probability density distributions for reference model journey fare zone use. Kutsuplus journeys for phases 3 and 4.

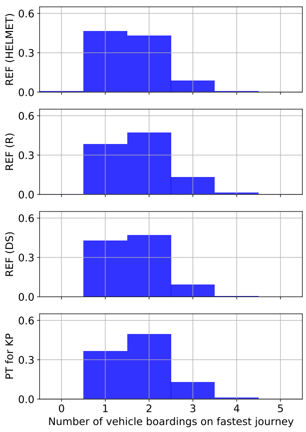
Boardings

The number of boardings for HELMET and DS reference model journeys seems to be slightly lower than for PT alternatives for Kutsuplus. It is intuitive that HELMET sampled journeys require less boardings, as they are often shorter than the journeys of other models. As the HELMET sampled model also reflects travel demand, it seems probable that the PT network has been constructed in a manner that minimizes the number of required boardings for high demand routes.

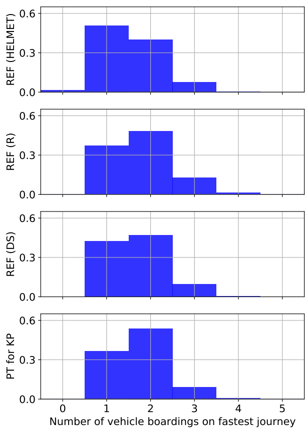
b_{fast} (Figures 5.37a, 5.37b, and 5.37c), is lower for the HELMET model than other models. The DS model also features less boardings. PT alternatives for Kutsuplus, R and DS are similar.

As we inspect b_{min}, we note (per Figures 5.38a, 5.38b, and 5.38c), the same trends. HELMET reference journeys require the least amount of boardings for MPH, EPH, and DT. The other reference models are roughly equivalent.

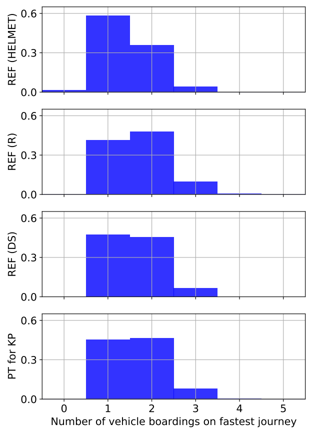
The same trends also hold for b_{mean}. b_{mean} is visualized in Figures 5.39a, 5.39b, and 5.39c.



(a) MPH

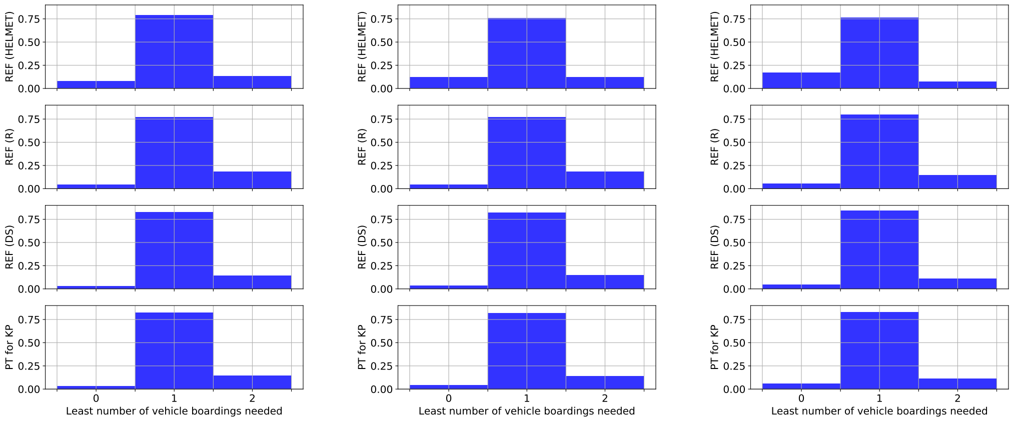


(b) EPH



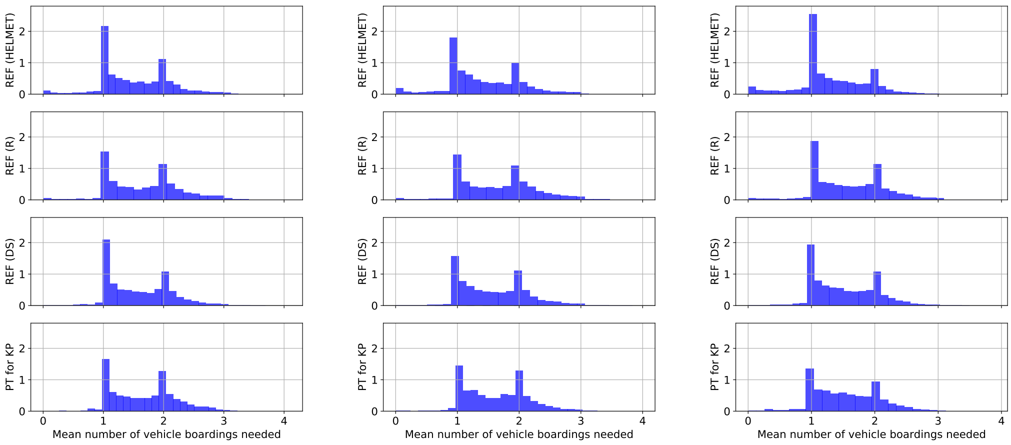
(c) DT

Figure 5.37: Probability density distributions for b_{fast}. Kutsuplus journeys for phases 3 and 4.



(a) MPH (b) EPH (c) DT

Figure 5.38: Probability density distributions for b_{min}. Kutsuplus journeys for phases 3 and 4.



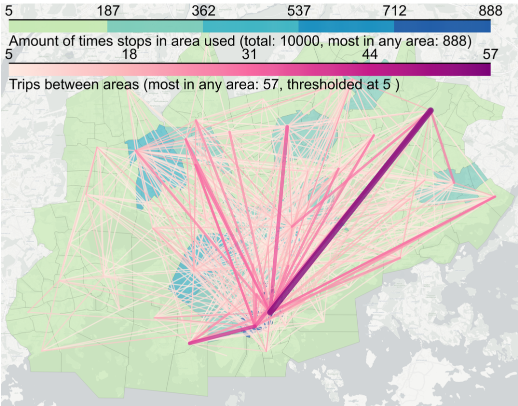
(a) MPH (b) EPH (c) DT

Figure 5.39: Probability density distributions for b_{mean}. Kutsuplus journeys for phases 3 and 4.

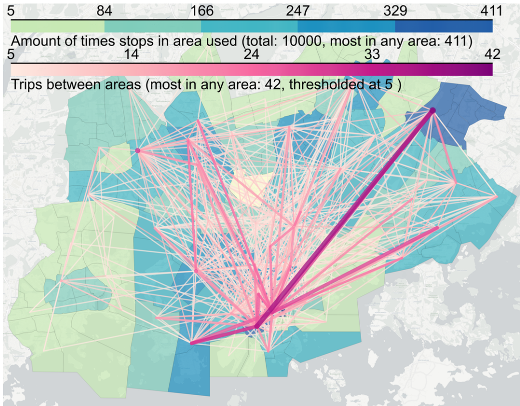
Spatial demand

We visualize demand of the reference models on a map by drawing demand lines between prediction zone (ENN) polygons in Figures 5.40 and 5.41.

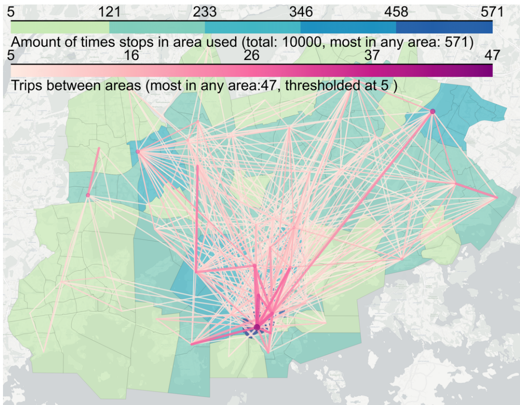
The HELMET model depicts the high demand of the city center through north-south links, especially during MPH and EPH (Figures 5.40a and 5.40b). Still, during MPH and EPH, HELMET demand is centered much more east and north than Kutsuplus demand. For DH (Figure 5.40a), HELMET demand is also centered around the northern and eastern regions of the service area, while Kutsuplus demand is more to the west.



(a) MPH demand (HELMET), thresholded at 5 journeys



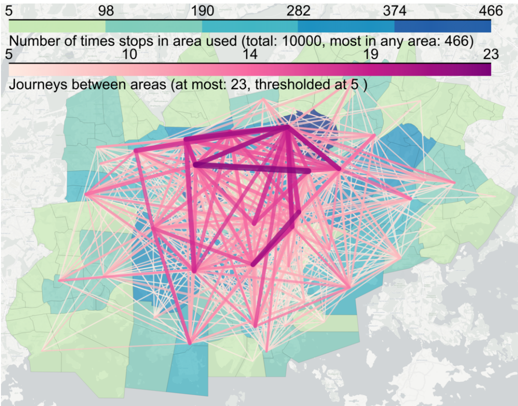
(b) EPH demand (HELMET), thresholded at 5 journeys



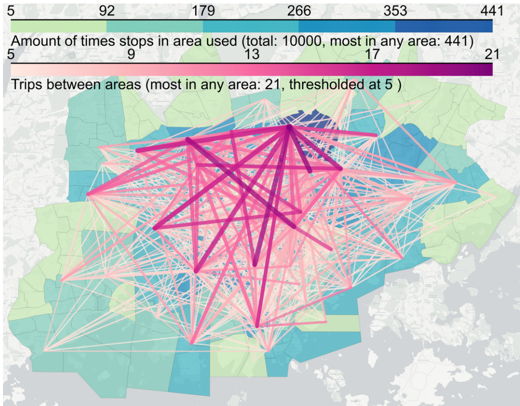
(c) DH demand (HELMET), thresholded at 5 journeys

Figure 5.40: HELMET reference model's demand on prediction zone (ENN) polygons, with demand lines. Demand direction highlighted by polygon background color. Background map: © OpenStreetMap contributors, © CartoDB

The random (R) and distance sampled (DS) models, in Figures 5.41a and 5.41b respectively, are centered much more north. These models effectively ignore the city center, but they also show cross-traffic demand lines, which visually do resemble Kutsuplus usage more closely than the HELMET model. The R and DS models also feature more demand to the west than the HELMET model, but the northern focus makes the patterns quite different from Kutsuplus demand.



(a) Demand (DS), thresholded at 5 journeys



(b) Demand (R), thresholded at 5 journeys

Figure 5.41: Distance sampled (DS) and random (R) reference models' demand on prediction zone (ENN) polygons, with demand lines. Demand direction highlighted by polygon background color. Background map: © OpenStreetMap contributors, © CartoDB

We inspected changes in demand between Kutsuplus and the reference models through prediction zone (ENN) polygon scatter plots, but we found demand to be very different. Significant differences in demand were to be expected for the HELMET sampled journeys per Section 5.1.3, where we noted Kutsuplus demand appears cross-traffic. But, we could find no patterns for R or DS sampled journeys either. Thus, these plots have been left to the Appendix as Figures B.9, B.10 and B.11.

Chapter 6

Discussion

6.1 Kutsuplus characteristics

6.1.1 Summary of results

Kutsuplus was characterized in the previous chapter. Based on the results we note that Kutsuplus was not often used by multiple passengers on a journey at the same time. Per Table 5.1 the journey price for Kutsuplus trips increased significantly over the years, from around 3.31 € per trip in 2012 to 7.15 € per trip in 2015, while the average journey distance and duration decreased. Increases in pricing are to be expected as Table 2.3 shows that pricing was increased significantly over the years as the service became more popular (per Table 3.3). It seems the pick up accuracy of Kutsuplus with regards to the pick up estimate was quite poor, especially during rush hours. We assume the estimate was given to customers, so they would know when to be at the Kutsuplus stop. This raises questions of whether the service had issues in avoiding congestive collapse, even though Metropol research considered the phenomenon.

The most active service phases of Kutsuplus clearly demonstrate a PT typical peak structure, with a narrow morning peak and a broader afternoon peak. While the peak nature of Kutsuplus largely resembles that of PT (see Table 5.2) especially the Kutsuplus MPH seems to be timed significantly later than for PT. It is also worth noting that a significantly higher portion of morning rush trips start during the Kutsuplus MPH (around 55%) than HSL PT trips start during the HSL MPH (around 47%). Even the Kutsuplus EPH is timed later than for HSL PT, though the demand seems to be much more evenly distributed with only around 35% of evening rush trips starting during the EPH when compared to around 46% of HSL PT. This might be because the on-demand nature of using Kutsuplus requires a more lenient travel window than taking a regular bus line.

Whereas the HSL HELMET 2.1 PT demand model largely features demand from and to the city center during MPH and EPH, the journeys made with Kutsuplus appear to follow a cross-traffic trend. As a common feature for HELMET and Kutsuplus demand, both feature high demand for the city center. But whereas the HELMET model has a very clear direction for demand (*suburbs* $\rightarrow$ *center* during MPH, *center* $\rightarrow$ *suburbs* during EPH) Kutsuplus does not. The DH demand of Kutsuplus resembles HELMET demand, which might indicate that Kutsuplus was used in a quite flexible manner.

Kutsuplus demand is largely centered to the west side of the service area, whereas HELMET demand is focused in the northern and eastern parts. Especially demand by the east metro line seems to have been quite low for Kutsuplus. In practice, there are none or very few journeys between Ruoholahti and Itäkeskus, while the demand in Lauttasaari seems proportionally quite large. This might be explained by socioeconomic differences or the need for a transfer at a hub terminal like Kamppi or the Central Railway Station.

It was found that the Kutsuplus service demand on Fridays did not differ from weekdays. This is important to note as PT services typically have extended operations on Fridays (weekend nights), with potential demand surges in the evening [24, 29, 34, 39]. Seasonality was inspected for 2015 as well, through representative months being March and October for working months and July for a vacation month. We highlighted some demand changes between vacation and working months, but it is plausible that vacations of a few frequent travelers cause these. As nothing significant stood out, further seasonal changes are left for research with access to more journey data, where month level changes could better be quantifiable.

Kutsuplus service classes were inspected, but no significant differences to normal Kutsuplus operations were found, besides an increased or decreased price. This is not very surprising as for example [62] has noted that the classes should have been based on real differences in service level, like journey duration. Some limitations for the service class inspections were caused by the relatively low number of available Fast journeys and the lack of identifiable users. It might have also been that Fast customers had vehicles more readily available through the ordering interfaces, which would make strict journey duration comparisons undescriptive. Unfortunately, it is not possible to quantify failed order attempts.

While no general trends were found for different Kutsuplus age groups, some slight trends could be observed with regards to PT fare zones. The age group 18–29 seems to have used Kutsuplus relatively often for MPH regional journeys. While the age group of over 65-year-olds had a strong trend to use

Kutsuplus within Helsinki, these trends could be caused by a few frequent users. Still, as university students (e.g. in the Otaniemi campus region) do not usually have mandatory attendance, the possibility to use Kutsuplus as a flexible form of school transport sounds plausible, and in line with service goals.

We note responses in [98] were heavily skewed towards older age groups as opposed to the age groups specified in the journey data used. The same holds true for the number of passengers on a journey, as over 10% reported to have ordered a group journey [98]. In reality, very few Kutsuplus journeys were done in a group. The spatial demand characteristics obtained [98] seem to roughly correspond to realized journeys, as does the distance distribution, though the role of the city center seems slightly exaggerated in [98].

6.1.2 Study limitations and future research questions

While the characterizations obtained are not directly expandable to a broader on-demand PT context they provide unique insight to the realized journeys of a relatively long lasting on-demand PT service pilot. The trends observed would have to be completely re-evaluated if the relatively small service area was changed, but noting that ordered services may feature PT typical demand peaks is not often encountered in literature.

The very late and relatively vague service area expansions are a clear limiting factor when considering very long journeys spatially or temporally. The Kutsuplus service area was only expanded to its full capacity presumably at some point in October 2015, some months before the service ended.

Public Holidays are either supplemented by additional PT or lacking in transportation options, for HSL these are listed in [24, 29, 34, 39]. Kutsuplus effectively did not operate during public holidays like Christmas, Easter, and Midsummer. From the journey data it is apparent that Kutsuplus operated normally during school holidays like Fall vacation in October (Finnish: "Syysloma") and Winter vacation in February (Finnish: "Hiihtoloma"). But because these vacations were limited to only a couple of days during each year and affect mainly younger students and their families, this thesis ignored potential effects.

There is still some minor noise in the journey data, with some Kutsuplus journeys having an unreasonably short duration. The reason for the noise is unclear and the pre-processing used in this thesis was intentionally kept minimal, as the data available is already limited. If co-operation with data providers is possible, it would be good to recognize what has caused this, and filter out invalid entries.

If it was possible to uniquely identify users it could be interesting to research potential changes in detail. It would be interesting to observe the routing and load distribution between the Kutsuplus vehicles in practice. This would enable considering service efficiency and analyzing how well service congestion has been dealt with. If demand about journey requests in the web service was available, it would be interesting to know how often vehicles were not available. The problems with users and vehicles not being identifiable are highlighted especially when frequent users can not be reliably identified and they may skew demand. If potential trip chains and frequent users could be identified it might enable much more interesting characterizations.

If more journey data was obtained it would be especially interesting to study the service in more detail. Effects of weather were ignored, but hourly historical weather data is readily available by the Finnish Meteorological Institute [67].

Kutsuplus had campaign days with free rides on 14th of February 2013, 14th of February 2014, and 31st of May 2014 [44], but these were unfortunately not included in the journey data set available. The campaign days could provide a concrete demo for high-demand situations. It would also be interesting to see if these campaign days were effective in attracting new users. Unfortunately, it is not possible to know how much in advance a customer wanted to or could order pick up. Different variations were tested per [44], but not detailed.

HESY (Helsinki region disaggregate choice models) [21] would also be interesting in more qualitative research. Unfortunately, with the journey data available, it is not plausible to generalize trip purpose and social status as opposed to research in [98] and [44].

Earlier research on routing on-demand transport has noted that most of the trips made with Kutsuplus were almost like subsidized private taxi journeys, with the algorithm being considered one of the most advanced on the market [51]. Based on the results of this thesis it seems departure timing of Kutsuplus journeys still had some uncertainty, but unfortunately it does not seem possible to investigate the closed-source algorithm in more detail.

6.2 Comparing modes of transport

6.2.1 Summary of results

When comparing modes of transport, it was found that Kutsuplus was usually faster than PT, biking, and walking. Kutsuplus was on par with private cars, assuming ideally that journeys start from bus stops at the same time. Even if the total journey time would be shorter for cars, considering the time spent for ordering a service, the effort required may still be comparatively high. Low effort might work in favor of Kutsuplus, which has been designed with a high-end IVT experience in mind. While PT required planning, and was not generally faster than Kutsuplus, the mean wait time at the stop on spontaneous departures was relatively short, when compared to the amount of waiting Kutsuplus sometimes required after the initial departure estimate.

In on-demand transport, UberBLACK was quite expensive compared to alternatives, while Taxi was priced slightly above UberPOP. Private car marginal costs are expectedly very low, but the characterizations done consider the environment in which Kutsuplus was used.

Trips inside Espoo were not popular, even though they were relatively so for the HELMET demand model (Figure 5.36). This is likely due to the bus trunk line 550, which effectively operates close to the edges of the Kutsuplus service area, exactly in the Espoo areas Kutsuplus also served (Leppävaara-Otaniemi-Tapiola, Figure 6.1). The trunk line has a short headway during rush hours and operates longer than Kutsuplus daily.

Figure 6.1: Route of HSL bus 550, the gray vertical line is the region border between Espoo (left) and Helsinki (right) [93]

We considered different amounts of walking to enable sensitivity and accessibility analysis for the PT journey alternatives. Comparing 0.5km to 2.0km walk cutoffs as the amount of walking decreases the journey duration and number of vehicle boardings increase. Especially journeys with the least number of boardings become significantly slower, since some Kutsuplus journeys could have been completed quickly on foot. Every 100th Kutsuplus journey becomes very impractical when walking is limited to 0.5km and every 20th journey could have been walked if 2.0km walking legs are allowed. Per Table 5.6, there does not seem to be a connection based purely on age groups and impractical walking. Still, it is quite clear that a significant portion of Kutsuplus journeys become impractical when walking was limited for PT, thus Kutsuplus seems like it was significantly more accessible in this regard.

6.2.2 Study limitations and future research questions

Marginal costs are likely the most reliable valuation for a mode choice decision, but in practice using a private car or even a bike in an urban area often requires significant cognitive effort and extensive parking considerations and potential fees as well. In practice, this is the price gap that needs to be bridged so that consumers would opt for a more expensive mode of transport. But quantifying this would be a very qualitative matter outside the scope of this thesis.

In addition to ignoring mode convenience factors and journey purpose, we only compare journey alternatives between two PT stops. As PT stops provide no inherent origin-destination value to travelers, they leave much unsaid about the full journey chain. With more information about user locations it would be interesting to consider more in-depth OVT methodology, such as approximating building-level journey impedance [2].

PT vehicle choice considerations were also not studied in this thesis. These would be possible with the current data available. A potential hypothesis for research could be that Kutsuplus was typically not used when good access to rail or trunk bus routes was available.

6.3 Reference models

6.3.1 Summary of results

We generated reference PT journeys using three different kinds of sampling. The reference journeys were in general more spread out both spatially and temporally, and the main variation seems to be in polygonal demand, not in distance travelled per unit time. Looking at fare zones, we noticed that Espoo journeys are more common in the HELMET model whereas the portion of regional journeys is significantly larger in all other models than the HELMET model. The amount of Espoo journeys could likely be explained by the trunk line 550. There seemed to be a slight trend for reference journeys of the HELMET model to require less boardings than Kutsuplus journeys.

The most prominent patterns of the different reference journeys are apparent in spatial visualization. Kutsuplus demand was considerably different from the reference models. Only the HELMET reference model considers the high demand of the city center whereas the random and distance sampled models are centered much more north. On the other hand, the random and distance sampled models contain cross-traffic patterns which do resemble Kutsuplus usage more closely than the HELMET model.

The reference journeys show that the PT infrastructure in the Kutsuplus service area is quite good. This does not come as a surprise, as the HSL SAVU model also implies accessibility should be good. Though, these results do contradict user experiences in post-shutdown questionnaire responses ([98], detailed in Section 2.4.4), as it can not be concluded that Kutsuplus would have been used when PT options were sub-par.

6.3.2 Study limitations and future research questions

The reference models are quite ad hoc, with realized service area and the stops used based directly on the journey data. This has likely caused a skew in results. It is possible that if we also considered HSL bus stops which were not used in the Kutsuplus journey data, we would obtain very different results. On the other hand, this would also induce a bias, as Kutsuplus users often departed from virtual bus stops, which probably get slightly longer PT journey durations than random HSL PT stops would.

The HELMET PT demand data we sample for the HELMET reference model provides the closest reference we have for real PT usage. Still, it has been designed for a much larger area. In this thesis, we simply ignore demand from and to areas not within the deduced Kutsuplus service area. A heuristic which would account for polygons actually used could be efficient in removing noise caused by the strong eastern region demand, which was not actually served by Kutsuplus.

The DS model let us compare journeys which were as long as realized Kutsuplus journeys, considering Euclidean distance. Unfortunately, the model is heavily skewed north, which makes further demand considerations unattractive. With relatively small changes it ought to be possible to for example center the model in the Helsinki city center, which could provide a more interesting reference.

The R model provides a fine baseline heuristic, but the implementation suffers from the stops used, as areas with many stops get much demand. Still, while R is a model that very roughly samples potential connections, it produces relatively comparable results to PT alternatives for Kutsuplus.

Chapter 7

Conclusions

Upon characterizing Kutsuplus, we found that temporal demand resembled a PT typical demand peak structure, but Kutsuplus featured a more lenient peak hour structure than PT, possibly due to the flexible nature of the service. The spatial demand of Kutsuplus journeys was largely cross-traffic when compared to PT in the region. Surprisingly, even though the routing algorithm has received much praise, the Kutsuplus service was found to be relatively tardy with regards to pick up timing. On average, the bus was found to be over four minutes late from the estimate.

When considering journey alternatives for Kutsuplus journeys, it was found that after a successful pick up Kutsuplus was indeed a fast choice compared to PT for the same journeys. Journey durations were often comparable even to private car usage. But Kutsuplus evolved frequently and required significant planning in advance. It is unclear how much in advance the bus could be ordered, whether transport was available when users attempted to order, and whether the bus would arrive on time. While Kutsuplus was a cheap demand-based transport alternative it was considerably more expensive than PT, which raises the question of LoS. The question users had to answer, considering also qualitative aspects, was whether Kutsuplus was cheap enough to compete with other forms of ordered transport and fast enough to justify paying a premium when compared to PT.

Based on reference model analysis the PT options for replacing Kutsuplus journeys were not found to perform poorer than the general PT available in the service area, thus the initial hypotheses regarding service use did not hold. There was a slight tendency in both boardings and travel durations to perform slightly worse for PT replacing Kutsuplus than for PT based on the reference models, but these differences were ruled insignificant.

This was the first time that spatial and temporal characteristics of Kutsuplus journeys have been considering using real journey data. The characteristics and background research will hopefully provide adequate reference for future research to expand upon. Aspects like the background service timeline and spatiotemporal visualizations have not been presented in a transparent manner before.

In future research, it would be especially interesting to consider more in-depth usage of the service. The existing journey data could be used to quantify whether Kutsuplus use was affected by accessibility of specific PT modes, like rail traffic. Access to more journey data would enable considering campaign days and seasonal and service area changes in a more detailed manner. In addition, if user and vehicle specific identifiers was made available, service congestion and user group specific behavior ought to be investigated, as this could enable recognizing day level trip chains and potential service niches. If detailed weather data was assessed it would also be interesting to know if for example rainy weather affected Kutsuplus usage or not.

For on-demand PT designed for the general public there is still very little quantitative research relating to realized service use. Kutsuplus was heavily subsidized and shut down in a way that left multiple open questions for research with incomplete leads. When considering piloting new kind of mobility services, especially using public money, planners should also prepare for potential pilot failure. This preparation should also include proper plans for retrospective analysis of the service, and how it was used.

References

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Appendix A

Computing private car costs

To approximate the fuel price for private cars we look at statistics from Kutsuplus operating years. We assume cars are standard sized, because most Kutsuplus journeys included only few passengers (detailed in Table 5.1).

There are three main classes of fuel sold for private cars in Finland, 95 E10, 98 E5 and Diesel, the prices for these are presented in Table A.1, with data sourced from [79, 85].

In what portions these fuel types are used is depicted in Table A.2 with data sourced from [80, 85]. Portions are based on the amount of all cars in the traffic register, with the portions of other car types ignored as insignificant. Portions of petrol types indicate portions of petrol, not all fuel types.

Based on the portions of fuel used, we compute the marginal cost for fuel consumption based on area type specific consumption estimates for private cars [81], listed in Table A.3. Street consumption is based on a load of 1.3 passengers, while road consumption assumes a load of 1.9 passengers. The averaged consumption is based on a 35% street portion with a load of 1.7 passengers. Consumption has been averaged for petrol in general. For identical cars there is research implying that 95 E10 and 98 E5 consumption is comparable [88], so they will not be differentiated further in the scope of this thesis. Street consumption is the value used for Kutsuplus as it suits the

Table A.1: Fuel prices (including tax)

Year	Price 95 E10 (€/ l)	Price 98 E5 (€/ l)	Price Diesel (€/ l)
2012	1.66	1.72	1.54
2013	1.63	1.68	1.51
2014	1.60	1.66	1.48
2015	1.46	1.52	1.29

Table A.2: Private car usage portions

Year	Petrol cars (%)	Diesel cars (%)	95 E10 petrol (%)	98 E5 petrol (%)
2012	78.0	21.9	55.0	45.0
2013	77.1	22.7	58.0	42.0
2014	76.3	23.5	61.0	39.0
2015	75.6	24.2	63.0	37.0

urban area of operations.

Table A.3: Private car fuel consumption

Area type	Petrol (l / 100 km)	Diesel (l / 100 km)
Street	10.0	8.3
Road	6.6	5.4
Averaged	7.8	6.4

Effectively the fuel price for each journey is computed as

$$price = euro/liter * liter_{consumed}$$

Where the price of euro per fuel per liter is defined as

$euro/liter = P(car_{petrol}) * (P(fuel_{E5}) * price_{E5} + P(fuel_{E10}) * price_{E10}) + P(car_{diesel}) * price_{diesel}$

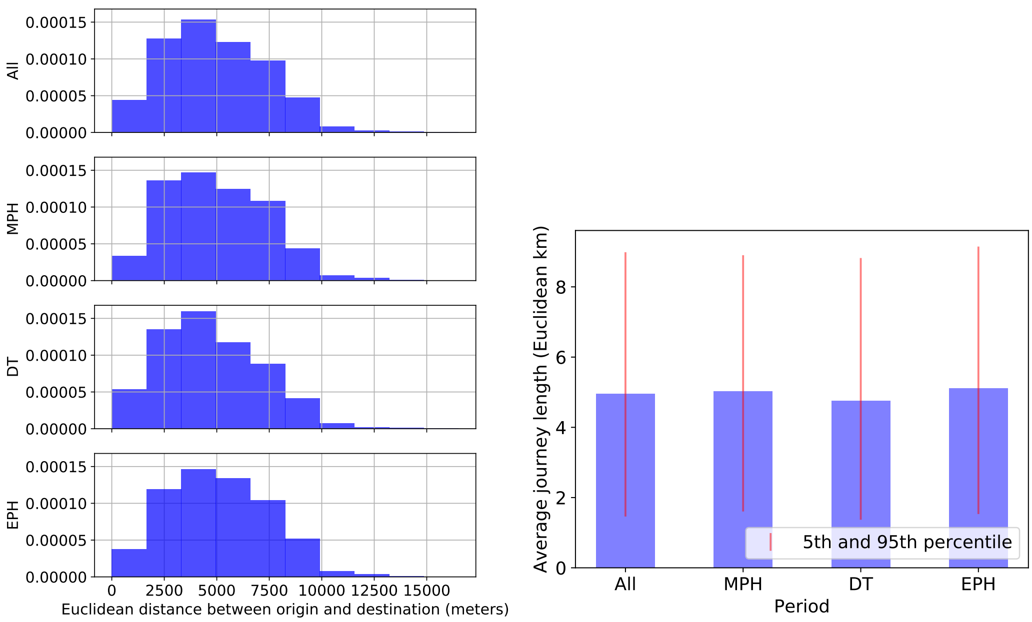
The number of liters consumed per kilometers driven is defined (where C stands for consumption) as

$liter_{consumed} = distance_{km} * ((P(car_{petrol}) * C_{petrol} + P(car_{diesel}) * C_{diesel})/100)$

Appendix B

Additional result plots

Journey lengths



(a) Probability density distribution for journey distance

(b) Average lengths

Figure B.1: Kutsuplus journey distance (Euclidean) variations for journeys of the third and fourth service phase. KP MPH (08:00–08:59), EPH (16:42–17:41) and DT (09:00-14:59)

While slightly shorter journeys were made during DT than during MPH and EPH the difference is minor (Figure B.1).

Age groups

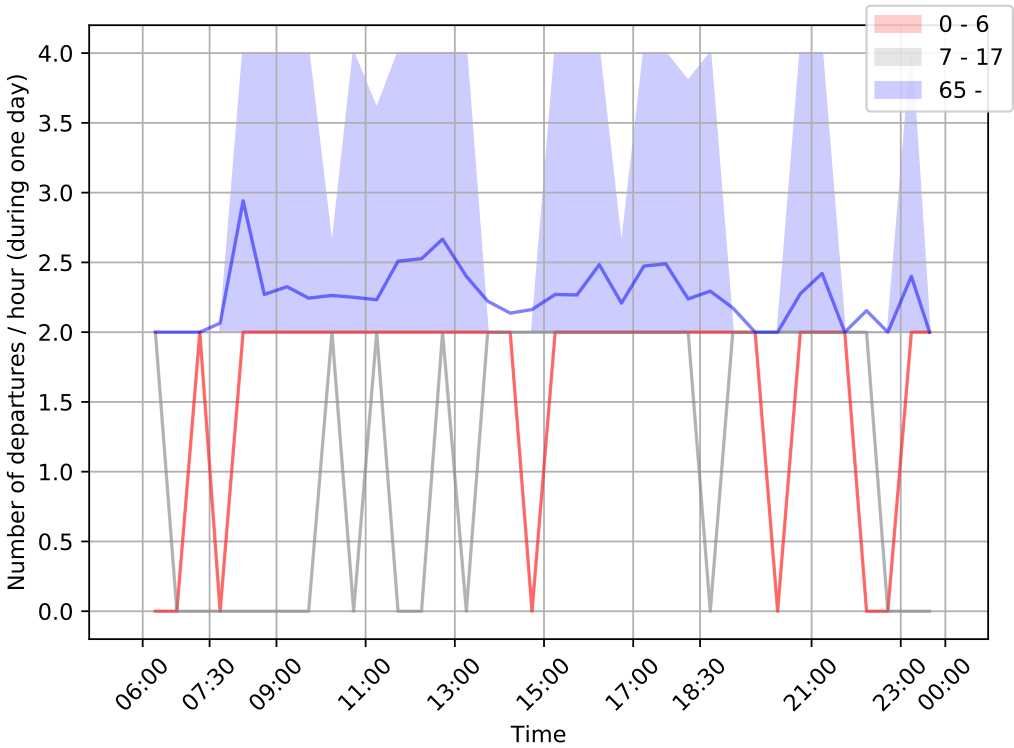
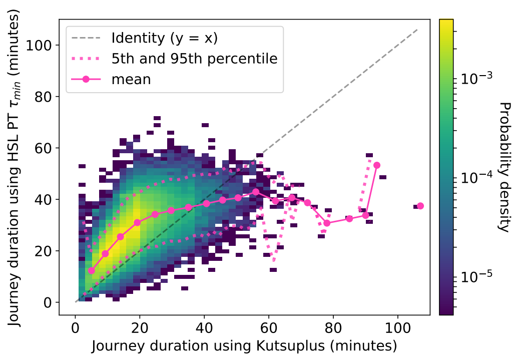
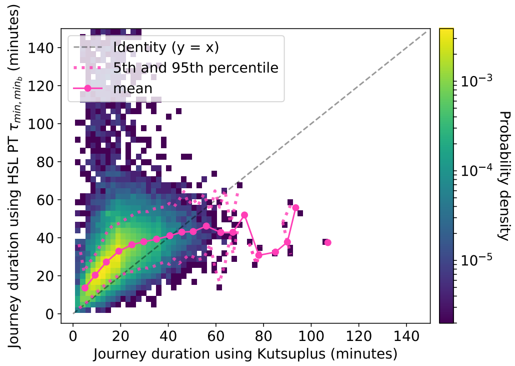


Figure B.2: Journey amounts for the most uncommon age groups

Journey duration



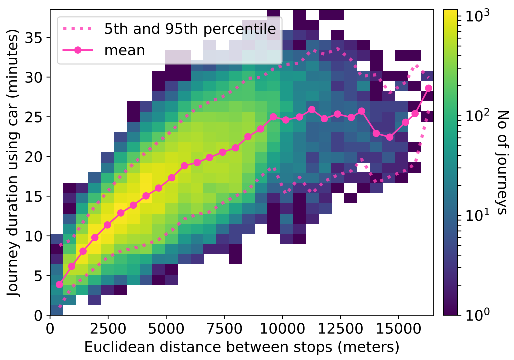
(a) Kutsuplus vs PT τ_{min}, PT is faster 6.9% of the time



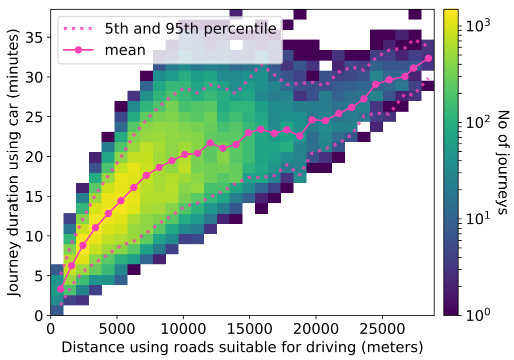
(b) Kutsuplus vs PT τ_{min,min_b}, PT is faster 6.0% of the time

Figure B.3: Journey durations of all Kutsuplus journeys against PT as a mode of travel, using a 0.5 km walking cutoff

Journey alternative duration as a function of distance

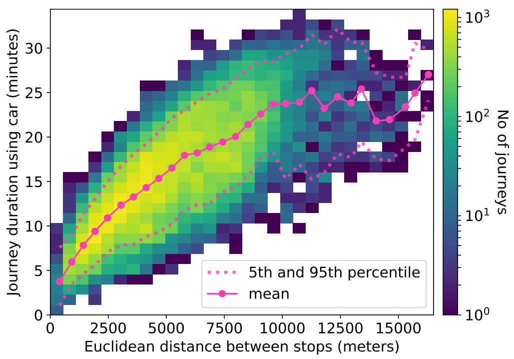


(a) Euclidean distance (congestion weighted)

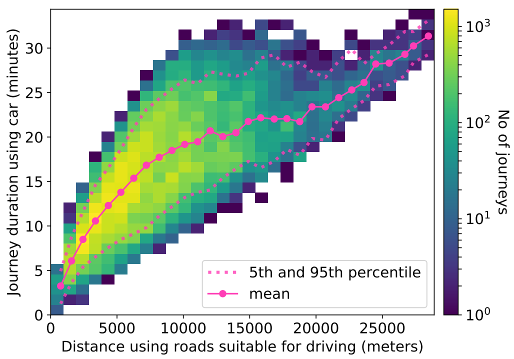


(b) Realized distance (congestion weighted)

Figure B.4: Duration of journeys by car as a function of distance



(a) Euclidean distance (uncongested)

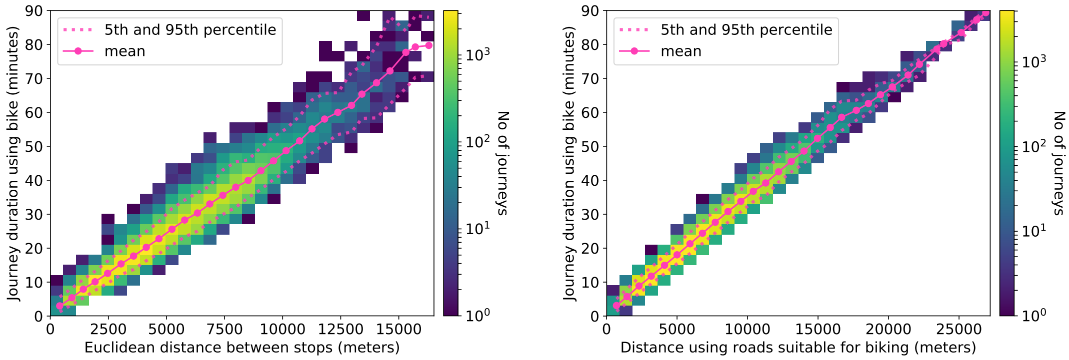


(b) Realized distance (uncongested)

Figure B.5: Duration of journeys by car as a function of distance

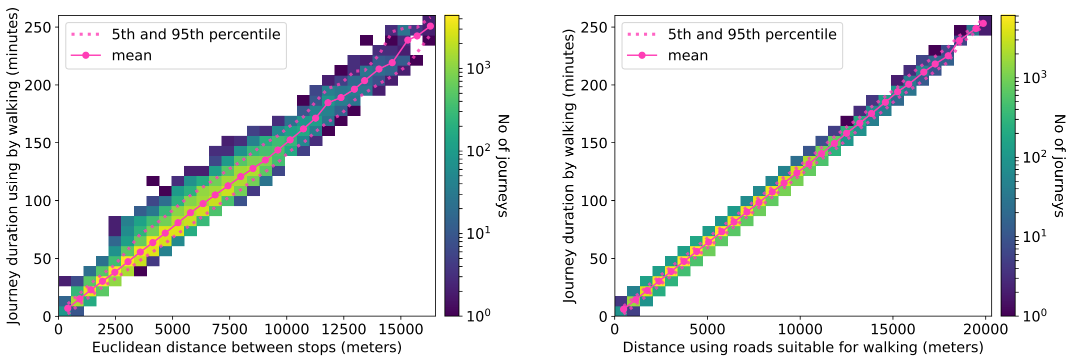
Private car journey durations increase as a function of distance traveled and as is to be expected (Figure B.5).

Cycling journey durations also increase as a function of distance traveled and as is to be expected (Figure B.6). The same holds for walking (Figure B.7). The varianace is much smaller than for driving or Kutsuplus.



(a) Euclidean distance (b) Realized distance

Figure B.6: Duration of journeys by bike as a function of distance



(a) Euclidean distance (b) Realized distance

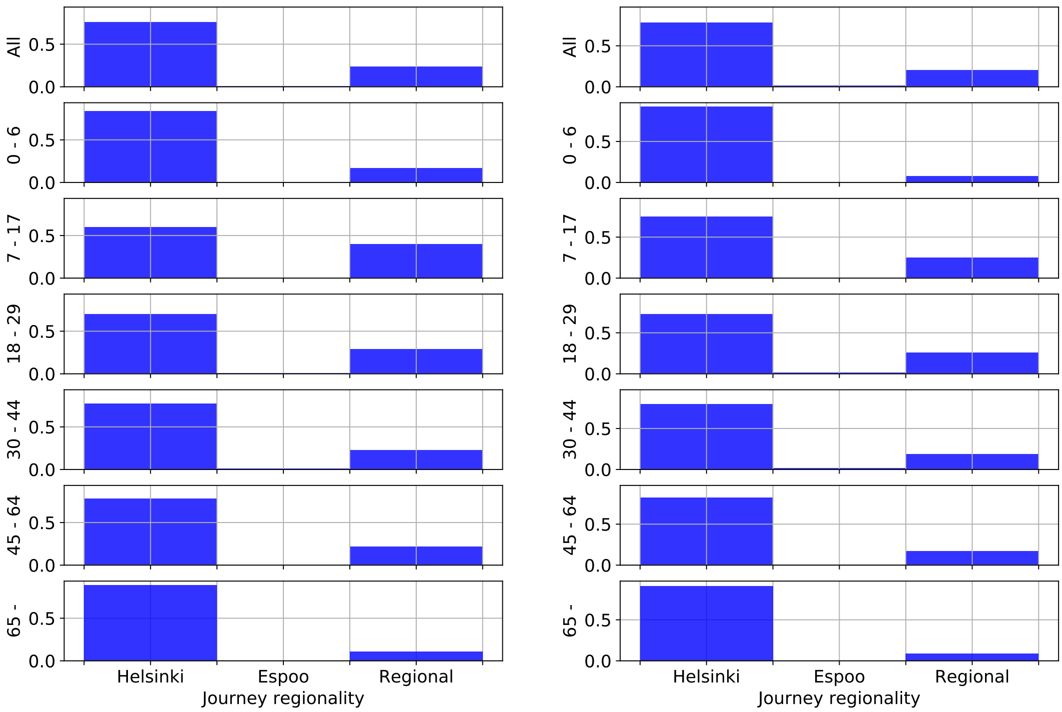
Figure B.7: Duration of journeys by walking as a function of distance

Fare zones

Table B.1: Number and portion of Kutsuplus journeys in different fare zones for different service classes

Type	All	Helsinki	Espoo	Regional
All +	82290	63742 (77.5%)	787 (1.0%)	17761 (21.6%)
Fast +	243	177 (72.8%)	3 (1.2%)	63 (25.9%)
Economy +	30657	23247 (75.8%)	435 (1.4%)	6975 (22.8%)
Normal +	51390	40318 (78.5%)	349 (0.7%)	10723 (20.9%)
All during Econ	38032	28917 (76.0%)	477 (1.3%)	8638 (22.7%)
Normal during Econ	7694	5729 (74.5%)	49 (0.6%)	1916 (24.9%)
Fast during Econ	203	153 (75.4%)	2 (1.0%)	48 (23.6%)
Econ	30135	23035 (76.4%)	426 (1.4%)	6674 (22.1%)
All during Fast	3254	2107 (64.8%)	78 (2.4%)	1069 (32.9%)
Normal during Fast	555	349 (62.9%)	5 (0.9%)	201 (36.2%)
Fast	203	153 (75.4%)	2 (1.0%)	48 (23.6%)
Econ during Fast	2496	1605 (64.3%)	71 (2.8%)	820 (32.9%)

+ Includes campus pilot.
Otherwise Econ and Fast are without the campus pilot



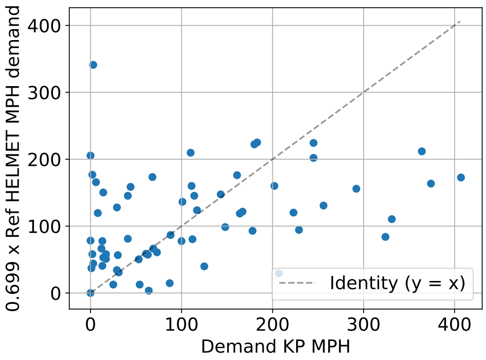
(a) KP EPH (16:42–17:41)

(b) KP DT (09:00–14:59)

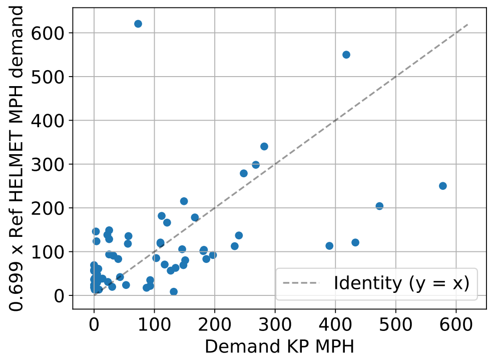
Figure B.8: Kutsuplus journey regionality probability density distributions for the third and fourth service phase

Reference models

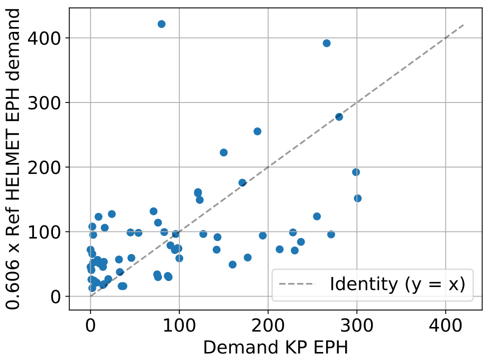
There are significant demand differences between the reference models and Kutsuplus for prediction zone (ENN) areas. This is clear for MPH (Figures B.9a and B.9b), EPH (Figures B.9c and B.9d), DH (Figures B.9e and B.9f), and in general (Figures B.10 and B.11). Heatmaps for demand between areas are not shown as demand is so different.



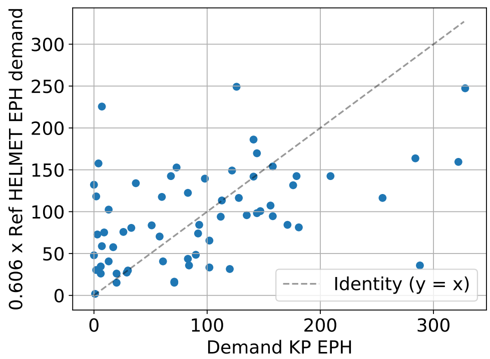
(a) MPH (origin)



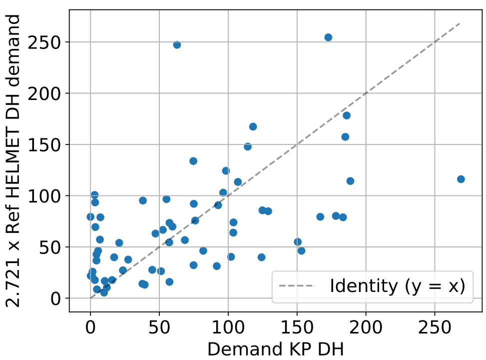
(b) MPH (destination)



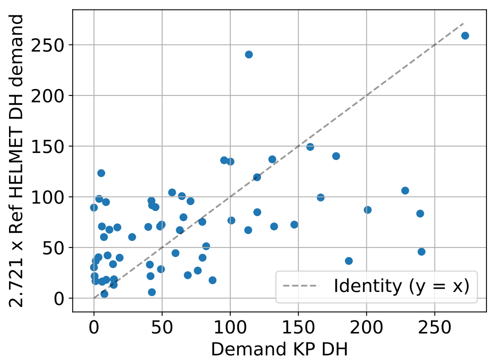
(c) EPH (origin)



(d) EPH (destination)

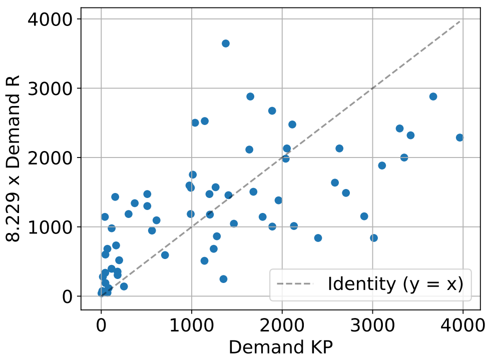


(e) DH (origin)

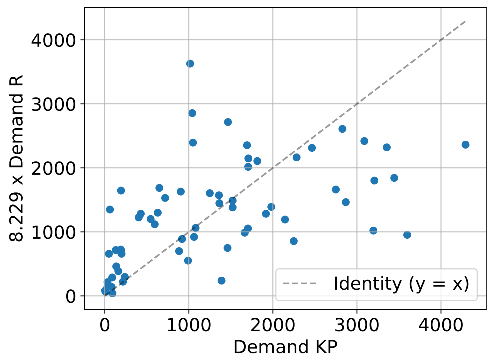


(f) DH (destination)

Figure B.9: Demand Kutsuplus vs HELMET reference model peak hours, using prediction zone (ENN) polygons. HELMET demand has been multiplied so that an equal amount of total demand is considered

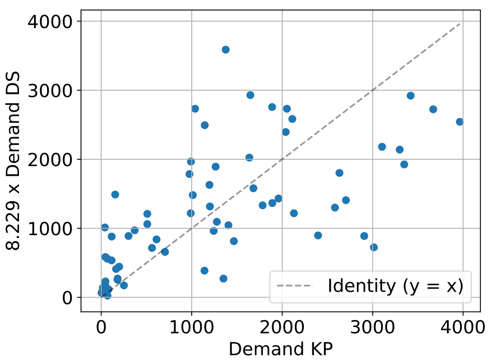


(a) Origin

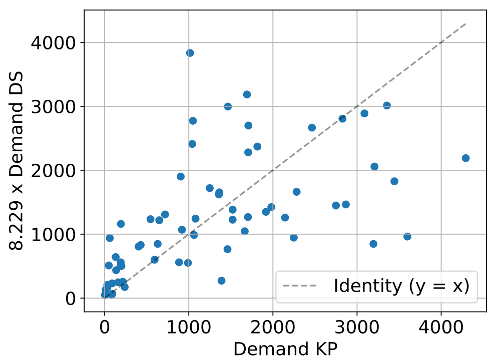


(b) Destination

Figure B.10: Demand Kutsuplus vs Random reference model, using prediction zone (ENN) polygons.



(a) Origin



(b) Destination

Figure B.11: Demand Kutsuplus vs Distance Sampled reference model, using prediction zone (ENN) polygons.